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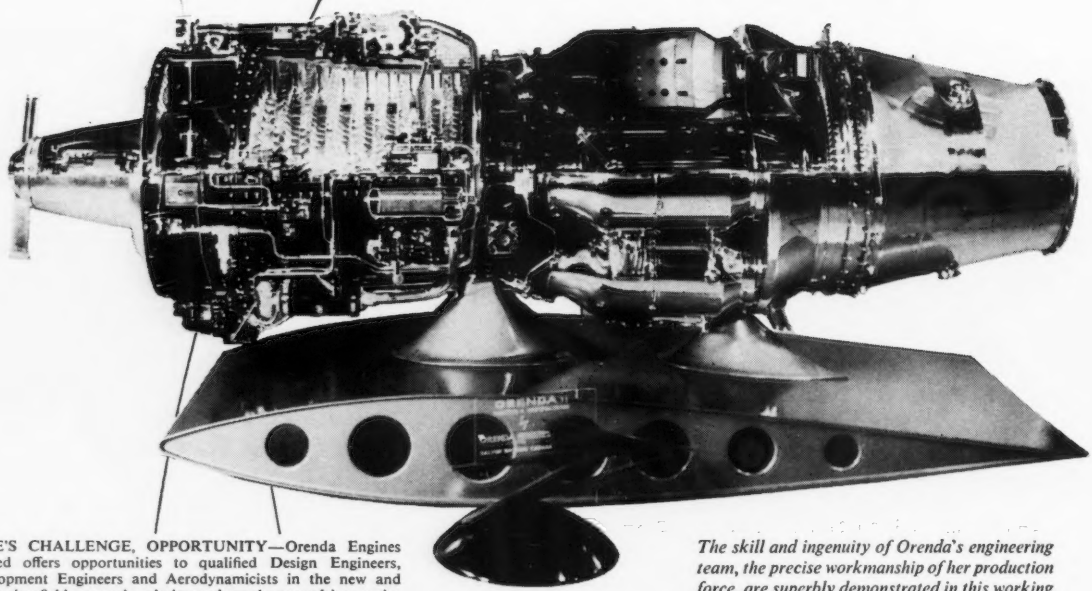

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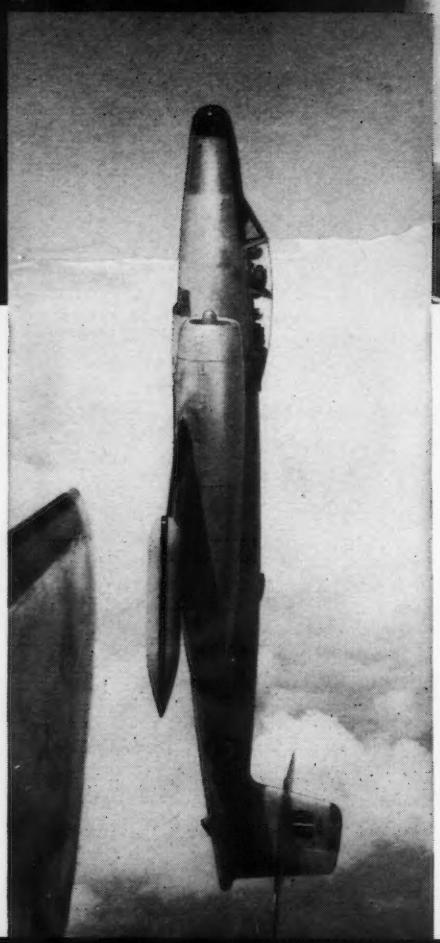

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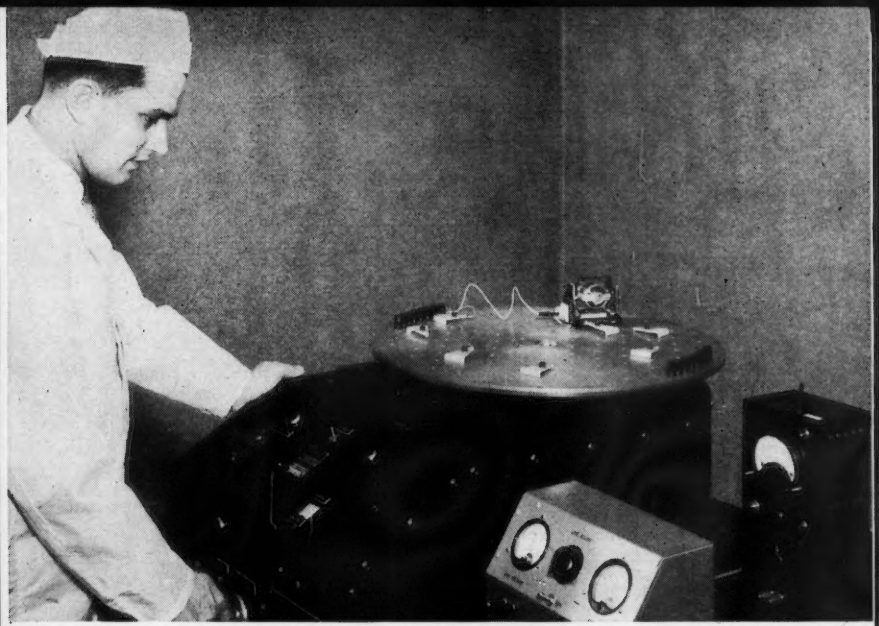

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Authors should prepare their material in accordance with the following directions:

Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscrips must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:–
(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:–
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,–Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . . "

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq., e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
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Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be,
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(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α–alpha".

In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. A/(B+C) rather than as

$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7–1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

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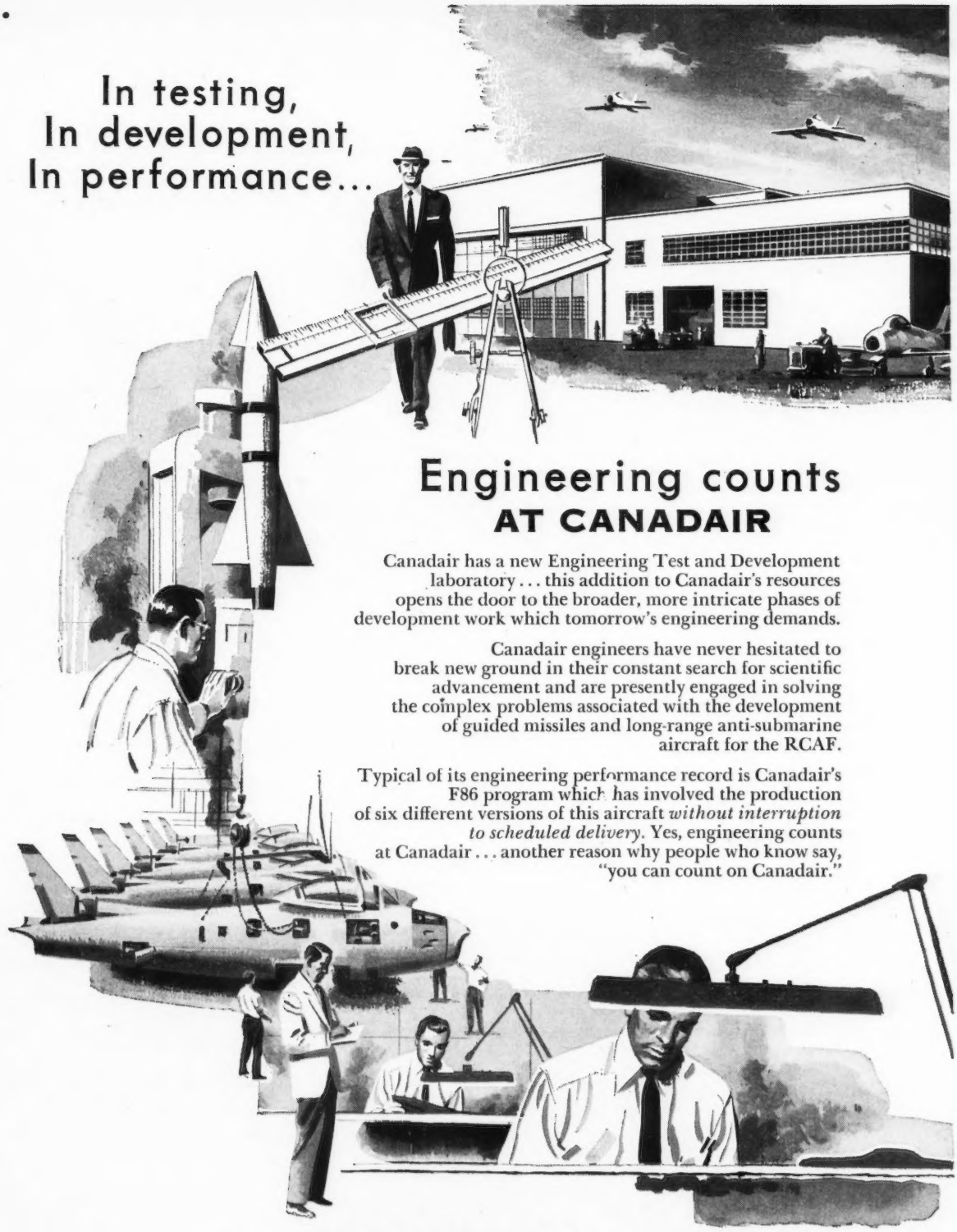

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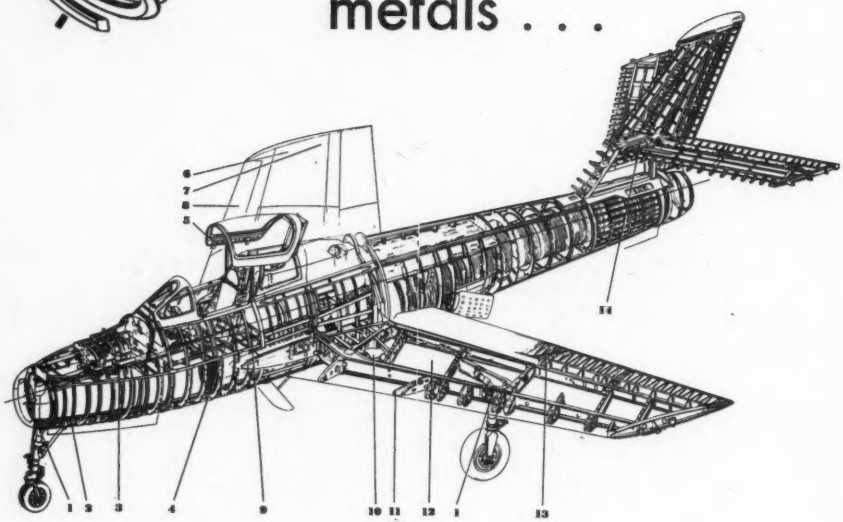

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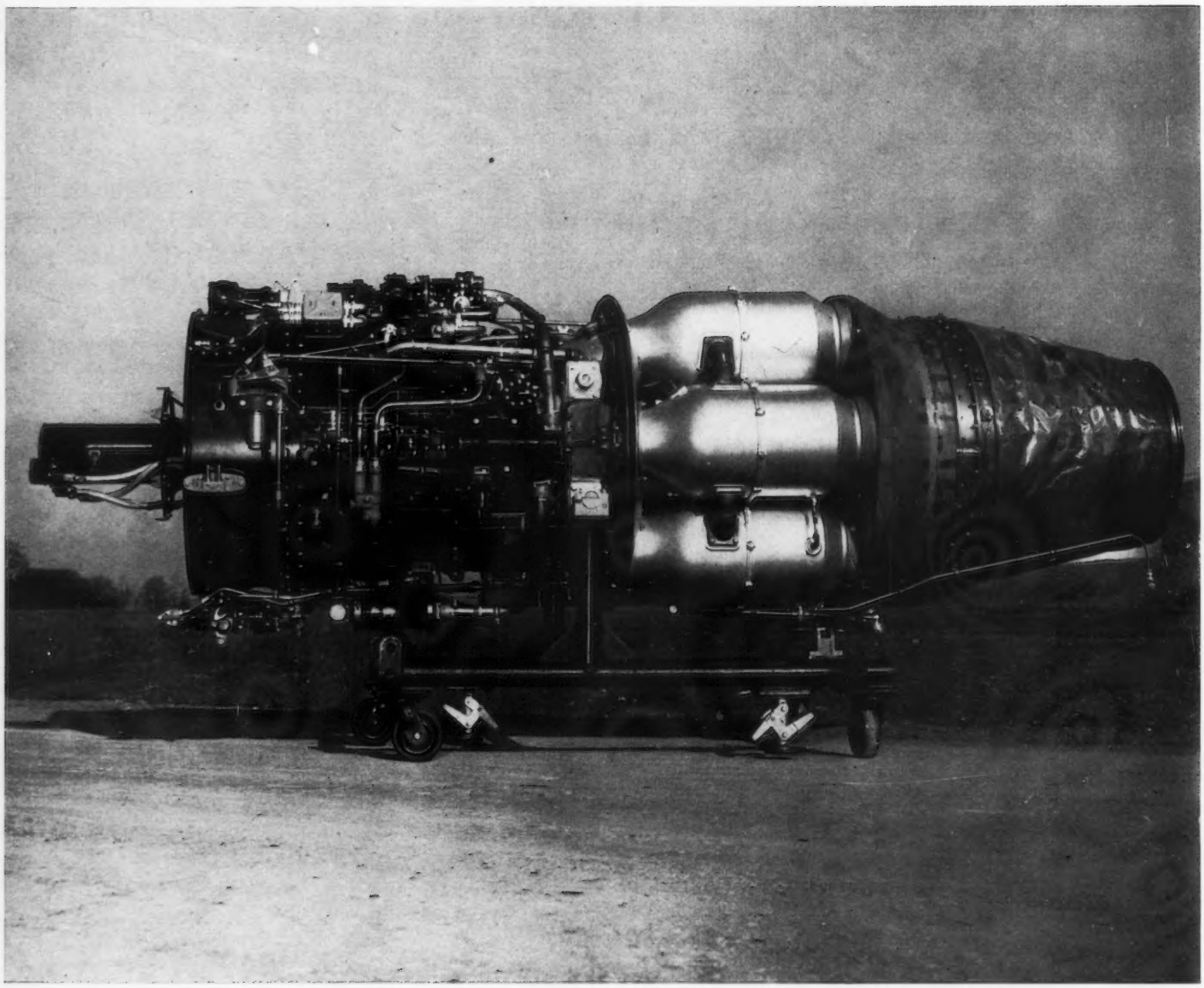
ORENDA



The Orenda 14 turbojet engine, manufactured by Orenda Engines Ltd. and installed in the Canadair Sabre 6. Rated at over 7,200 lb. the engine has a 10-stage axial compressor and 2-stage turbine. **A paper on the production of the Orenda appears on Page 93.**

EDITORIAL

ACROSS CANADA WITH THE R.Ae.S.

We have received from Dr. A. M. Ballantyne, Secretary of the Royal Aeronautical Society, the following account of his recent ten-day trip across Canada:

THE entry in my diary for the 7th July, 1955 reads—"—entered the land of the C.A.I."

That entry was more significant than I knew at the time, for throughout Canada, from West to East, we met many representatives of the C.A.I., and very pleased we were to do so.

I don't know whether to liken the growth of the C.A.I. to the growth of a lusty infant, or whether to deny the statement that Rome wasn't built in a day, for I saw every evidence that the growth of the Canadian Aeronautical Institute was quite phenomenal in its unexpectedness. That I have been honoured by being made an Honorary Fellow of the C.A.I. is now common knowledge; of this I am very proud, proud of being associated with the youngest of the sister societies, founded for the advancement of aeronautics.

As you will read, many members of the C.A.I. went out of their way to give us hospitality and entertainment, and we thrived on it.

VANCOUVER

On arrival on the 7th July, "we" consisted of Miss Pike, Mr. Deryck Smith, Mr. John Dunsby, my wife and myself; however, Miss Pike left the party at Jasper, and my wife and I left the other two at Toronto.

At Vancouver we were met by Mr. J. Bertalino and Mr. R. J. McWilliams, and straightway taken to our hotel. In the evening the male members of the party dined with Mr. H. D. Cameron and the Committee of the Vancouver Branch, while the ladies were entertained by Mrs. H. D. Cameron and Mrs. G. Ades. And we all talked, and talked, and discussed, and opined. And the evening passed very pleasantly. The following morning Mr. D. McLaren of T.C.A. took us sightseeing until we had to catch our train to Jasper.

EDMONTON

The journey through the Rockies, and Jasper itself where we spent a night at the Lodge, were interesting and beautiful but our next contact with the C.A.I. was in Edmonton. We were met there by W/C and Mrs. J. G. Portlock and Mr. and Mrs. C. C. Young. And we were pleased to see them. They took us to our Hotel (here we discovered that old Macdonald had more than a Farm) and wished us "good-sleeping".

Next morning W/C Portlock called for us and we paid a visit to Northwest Industries, where we were greeted by Mr. Pitfield, the Managing Director. At lunch Mr. Pitfield told us about the oil industry and the rises in fortune of some of Edmonton's citizens.

In the afternoon we visited the R.C.A.F. at Namao and heard of the winterization trials. Then we were taken (by buggy) on a tour of No. 7 Maintenance Store, which was housed in a hangar of gigantic dimensions. We were glad we were being conveyed around.

Although there is not yet a Branch of the C.A.I. at Edmonton, I imagine that there soon will be. They are making haste slowly. W/C Portlock and Mr. Young had collected together a goodly gathering to meet us in the evening, and again we talked. As always happens, had we been staying another day we have . . . This time it was an invitation to fish a lake a hundred miles north; no names, no poaching! And in a second Dominion I heard fishing stories. Here, unlike New Zealand, the emphasis was on quantity not magnitude. Some day I hope that I shall be able to take up that last minute invitation.

Next day, before we left for Winnipeg, we walked around Edmonton, sorely tempted to buy such things as Mackinaws, which looked very suitable for the usual British weather. Here another preconception went West. The Hudson Bay Company sold "Davy Crockett" outfits, and were not a purveyor and buyer of pelts only.

WINNIPEG

Edmonton to Winnipeg via Calgary. The T.C.A. Viscount touched down at Calgary and we learned that the Stampede was in progress—and me with a Ten-Gallon hat in my wife's hatbox. If only—. And so on to Winnipeg where we were met by Mr. R. T. Gibson, Secretary of the Branch, Mr. D. A. Newey and Mr. and Mrs. D. L. Aitken. On arrival at the airport in our comfortable Viscount my wife, thinking it looked coldish, put on her

coat. Outside it was 92°F and 93% humidity. The coat came off.

In the evening we strolled along Portage and admired the lights and the shops and found that the most popular colour in men's shirts appeared to be pink.

Next day we visited the T.C.A. Maintenance Hangars at the invitation of Mr. Aitken and saw their new Viscount Maintenance Dock and the No. 11 Viscount, which had arrived the previous day. It had flown through a hail storm and looked a bit battered. We were taken into the Engine Test Sheds, which were remarkably quiet.

Mr. Aitken took us to lunch at the Winnipeg Aero Club and Flying School, where business is extremely brisk. Any more pupils would embarrass them. And that is a good thing! At lunch we were joined by Mrs. Aitken and my wife, who had spent the morning on women's business.

In the evening we were entertained by the Members of the Committee and their wives, and it was a very pleasant evening. In the absence of the Branch Chairman, Mr. J. J. Eden, Vice-Chairman, acted as host.

Next day Mr. Newey called for us and took us to see Lower Fort Garry. I think I was expecting something like Fort George and so, until we went into the House, was a bit disappointed. However, Mr. Newey managed to get permission to show us over the house and cellars, and they proved well worth the visit.

Hitherto I had thought that Winnipeg "Goldeyes" were a baseball team, but at lunch found out that they were in fact the local fishy delicacy.

Mr. Newey took us for a quick visit to MacDonald Bros., now a member of the Bristol group. My wife was heard to mention that this was her first visit to an aircraft factory.

TORONTO

The transcontinental Super Constellation of T.C.A. picked us up at Winnipeg and dropped us at Toronto, where Mr. Ian Hamer was waiting for us. We had last seen Mr. Hamer in Los Angeles, so his was a well-kent and welcome face.

And now we saw Canadian hustle. We arrived at our hotel and within twenty-one minutes we had washed, shaved, changed and were on our way to the ferry to take us to the Yacht Club on Toronto Island.

By the time we reached the Island it was dark, and gradually we saw familiar faces. From the darkness would come a greeting and it would be someone whom we had met previously. Mrs. Hamer was the first to say "hullo" and it was an old friend talking. Mr. and Mrs. Luttman and it was a pleasure to see them look so well. Mr. and Mrs. Dick Richmond, again old friends. Professor and Mrs. Loudon, Dr. Patterson, Dr. Glass. And then "mirabile dictu", Mr. and Mrs. N. E. Rowe, whom we had last seen in Seattle, and somehow or other did not expect to see again until we foregathered in London. Old home week with a vengeance!

Since last I saw Mr. Luttman, he had become Secretary of the C.A.I., and a better choice could not have been made.

All too soon the last ferry came in and we crossed from the Island to Toronto, happily tired and contented.

OTTAWA

Next morning, immediately after breakfast, in a thunderstorm, we set out with Mr. and Mrs. Hamer for Ottawa. We stopped to say "hullo" to Mr. Hunt at Dowty Equipment, and at the Hamer House to pay our respects to the children. And it was still raining when we set off again for Ottawa.

We made a slight detour to see Perth. I have now visited three Perths—one in Scotland, one in Australia, and one in Canada—and although they are all lovely cities, Perth (Canada) gives place to neither of the others.

At Ottawa G/C and Mrs. D. M. Holman called for us and took us to the Mountain Lodge in the Gatineau Hills. Here Mr. J. L. Orr, the Chairman of the Ottawa Branch, made us welcome once more; and there was Dr. J. J. Green, accompanied by Mrs. Green! And again we talked!

All good things come to an end—only to make room for more.

Next morning at the Chateau, Dr. Green came round and we discussed his British Commonwealth and Empire Lecture, for the Past President of the C.A.I. has been invited to give this lecture in London on October 6th, 1955. My preview of his paper was rather hurried but satisfying.

My wife and I had a farewell lunch with Mr. and Mrs. Hamer; the farewell is only "adiosita", a short farewell, for we hope to see them in September in England.

MONTREAL

Mr. and Mrs. Luttman and Dr. Green saw us safely on to yet another T.C.A. aircraft and we soon reached Montreal, where Mr. M. Hildred (T.C.A.) and Mr. Dick Richmond, President of the C.A.I., were waiting to greet us. I strongly suspect that Mr. Richmond had forgone part of his holiday to be in Montreal to meet us.

Air Vice Marshal A. L. James and his wife very kindly entertained us in the evening. The A.V.M. is Chairman of the Montreal Branch. All four of us paid our respects to Sir William Hildred, for his son, who had met us at Dorval, had told us of Sir William's arrival.

And so our last evening in Canada was spent as pleasantly and happily as was the first.

In the morning Dr. Edward Warner, another old friend, telephoned us and gave up his time to tell us "hullo" and "good-bye" in practically the same breath.

We spent ten days in Canada: "venimus, vidimus, vincti sumus". We came, we saw and we were conquered, and that without hurt but pleasantly.

To the people who made our stay memorable we tell our sincere thanks, and these people are all those whom we met, named and unnamed here, not forgetting all the kind ladies who "showed the town" to my wife.

I should like to mention T.C.A. All along our route T.C.A. had "alerted" their people, and they made our "journeyings" as pleasant as could be. May we say a grateful thanks.

Once, twice, my wife and I have visited Canada;—"Here's to the next time".

Dr. A. M. Ballantyne,
Secretary,
Royal Aeronautical Society.

THE ECONOMICAL PRODUCTION OF JET ENGINES IN CANADA†

by E. K. Brownridge *

Orenda Engines Limited

SUMMARY

In a survey of the production of the Orenda engines, the author describes the problems associated with the training of manpower and the setting up of plant, facilities and a supply network where none existed before. The special requirements for the manufacture of gas turbine engines are discussed, with emphasis on the importance of flexibility and the need for close co-operation between design and production engineers to meet the demands of continuing development during production. The author issues a warning against imitation of the production techniques employed by others, which may not be appropriate to local conditions, and urges encouragement of initiative and imaginative thinking. In conclusion attention is directed to the need for constant refinement of design to reduce cost and facilitate production once peak production is reached.

In his lecture on "The Orenda and the Future"[1] Mr. Burt Avery explained many of the problems which confront the designer of a modern jet engine, and stressed the need for the closest co-operation between the Mechanical Design Engineers and the Production Engineers, during the early stages of development of an engine.

Today, I would like to continue that theme, and also tell something of our experience while putting the Orenda into quantity production.

In order to put the whole story into its proper perspective, I will recount to you a little of the Company's history. Ten years ago neither the Orenda jet engine, nor A. V. Roe Canada Limited had been thought of, although the Government had obviously considered the possibility of eventually manufacturing jet engines in Canada, because in 1944 it established Turbo Research Limited, as a Crown Company, situated in Leaside.

†Paper read at the Annual General Meeting of the C.A.I., in Toronto, on the 20th May, 1955.

*Vice-President, Manufacturing.

Figure 1. Production plant, Orenda Engines Limited.

In 1945 the Government decided that it should no longer remain in the Aviation Industry and would sell the assets of Victory Aircraft Limited, the wartime producer of Lancasters. Accordingly, various allied manufacturers were invited to consider the project. The outcome of the subsequent negotiations was that in 1945, under the guidance of Sir Roy Dobson, A. V. Roe Canada Limited was born as a member of the Hawker Siddeley Group in Britain.

In 1946 the operations which had been carried on by the Crown Company, Turbo Research Limited, were absorbed by A. V. Roe Canada and became the Gas Turbine Division. Later that year the new Division was

asked to undertake the design of a power plant for the new all-weather fighter—the CF-100—which was then on the drawing boards. On February 10th, 1949, the Orenda took its first breath and was approved by both the R.C.A.F. and the Government. As a result of this, and because of the world political situation, the first production contract for jet engines was signed by the Department of Defence Production in May 1949. A small pilot plant was planned at this time, and was to be capable of a maximum output of one engine per day. However, before this plant had produced its first engine the unfortunate Korean episode broke out. Two months after that event, in August 1950, the Government gave authority for the construction of a much larger self-contained production plant.

Work on the new plant began in May 1951 and continued until September 1952 when the plant, Figure 1, was officially opened by the Rt. Hon. C. D. Howe, Minister of Defence Production. During this period the transfer of the complete Pilot Plant operation to the new plant was also accomplished. Prior to the transfer, a total of only 30 Orendas had been built, but a great deal of experience had been gained which proved extremely valuable when we were setting up the new plant.

Recently the Gas Turbine Division of A. V. Roe Canada has become a Company in its own right, called "Orenda Engines Limited" having taken the name of its now well-known product.

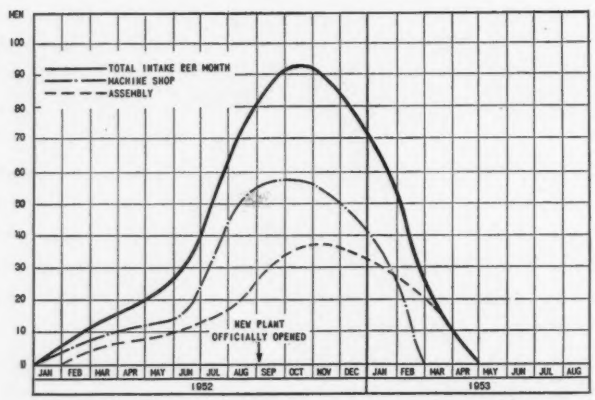

MEN
TOTAL INTAKE PER MONTH
MACHINE SHOP
ASSEMBLY
NEW PLANT OFFICIALLY OPENED
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG
1952
1953

Figure 2. Direct production manpower intake per month.

PRE-PRODUCTION PROBLEMS

Having a new plant was a great contribution towards solving our production problems; however, we still had the problem of manning it and keeping it adequately supplied with materials.

In January 1952, before we moved into the new plant, the company employed less than 200 direct production workers. To assist our Personnel Department in their task of providing the additional manpower, forecasts were prepared showing the monthly intake required in both the machine and assembly shops, Figure 2. Details were also provided as to the specific number needed in each of the various trades.

Our assembly shop requirements were mainly filled from the ranks of the top flight automotive mechanics

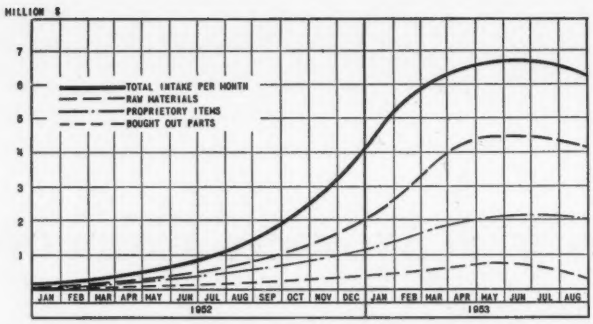

MILLION $
TOTAL INTAKE PER MONTH
RAW MATERIALS
PROPRIETORY ITEMS
BOUGHT OUT PARTS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG
1952
1953

Figure 3. Monthly intake of parts and materials.

in this country, and the many fine aircraft mechanics trained by the R.C.A.F. during the last war.

The machine shop presented a tougher problem because so much of our equipment was of the latest design, and included such machines as the semi-automatic Bullard Man-u-trols, which were then relatively unknown in Canada. All this meant that an extensive operator training program had to be undertaken in the plant to satisfy our needs. I think that the size of the problem we faced will be better appreciated when it is realized that between January 1952 and January 1953 our production manpower had to be increased by almost 500%.

During this same period a tremendous increase in the supply of parts and materials had to be arranged if we were to meet our production schedules. In fact our intake increased from around $500,000 per month in April of 1952 to more than $6,000,000 in April of the following year, an increase of 1200%, Figure 3.

Setting up the supply network to meet this demand was a prodigious task for our Procurement Department, because there were at the beginning of this time few manufacturers in Canada who were in a position to supply us with parts and material of the types, and in the quantities, that we would require. But with the co-operation of the Government in providing capital assistance, and of manufacturers in Canada, the United States and Britain, satisfactory sources of supply were eventually established. To make this possible, a total of more than sixty major sub-contractors had to be organized, many of whom built new plants in Canada, or expanded their existing facilities specially to supply us. Many of these companies were faced with the same problems which we had to face; those of expanding their facilities and staff at a terrific pace in order to meet our demands.

This critical expansion period posed a very great problem of scheduling and co-ordination to ensure that all the 3,500 parts reached the assembly line in the quantities and at the time they were required to meet the build schedules.

NATURE OF PRODUCT

Before describing the manner in which the new production plant was laid out and equipped, I would like to tell you something of the nature of the product and the unique problems it has for the manufacturer.

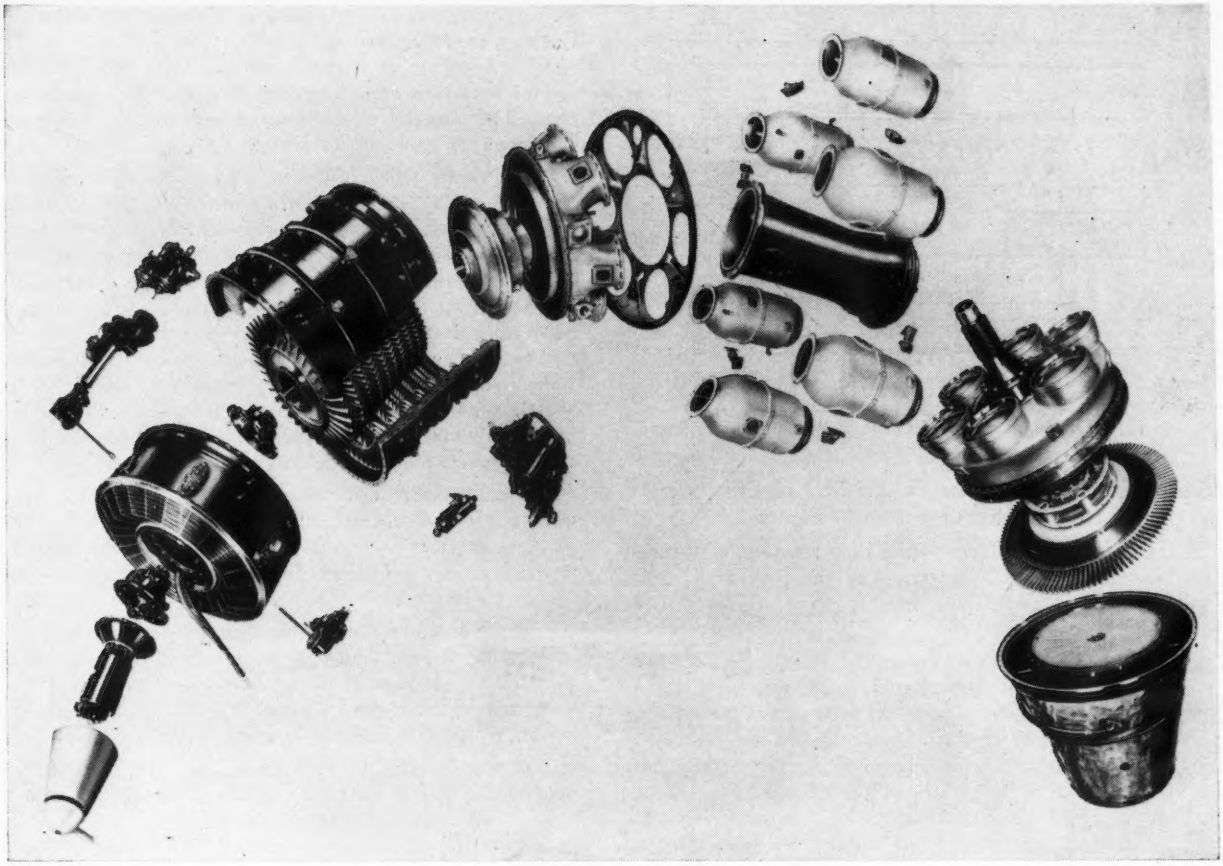


Figure 4. Exploded view, Orenda jet engine.

The Orenda, Figure 4, is an axial flow turbo-jet engine, and is composed of about 3,500 different items, and has in it a total of more than 16,000 parts; 1,700 of these parts consist of compressor and turbine blades. These are usually the controlling item in manufacturing an engine of this type due to the large volume required and their complex configuration. Much of the rear portion of the engine, the "hot" end, must be constructed to withstand hot gases of up to 1700°F for long periods of time. Within the engine are a large variety of metals ranging from the ultra-light magnesium castings used for the compressor casing to the tough heat-resistant steel alloy of the turbine blades and nozzle box. Many of the latter materials had never been successfully machined before this time. In order to adequately control the power available in the Orenda, a complex fuel system is required. The engine also is called upon to drive five different gearboxes, such as the oil pump and power take-off gearboxes. One other feature, which added to the difficulties of machining magnesium, aluminum and stainless steel alloys, is the extreme sensitivity of jet engines to small changes in dimensions or materials. For example, .001″ extra turbine tip clearance can result in a loss of about 15 lbs. in thrust.

Perhaps the greatest difficulty facing the manufacturer of jet engines, is the fact that their design is not sealed for production, but is modified steadily for increased performances. This constant development of an engine while in production is essential if the engine is to maintain its competitive position. Therefore, we as engine manufacturers, must lay all our plans with the clear understanding that in this business perpetual change is the order of the day.

As an illustration of this point, in the past three years since the Orenda production program got under way, a total of over 4,000 design changes have been introduced into production engines, each bringing its own individual problems of supply and incorporation. These were all incorporated without any significant interruption of the production program.

One of the most perplexing problems for Management, is at what point in its development should a jet engine be released to production. On the one hand, the later it is left, the better will be the first engines and the less trouble production will have. On the other hand, the earlier it is released the sooner production will know what their troubles are, and therefore the earlier a solution can be found and the production rate achieved.

Somewhere along this thorny trail, a happy medium must be found. If time were not important, but it always is, the ideal would be to release the engine to production immediately it had succeeded in passing its qualification test. However, under these "Utopian" conditions it would probably take around eight years to go from initial design to the planned production peak. In our

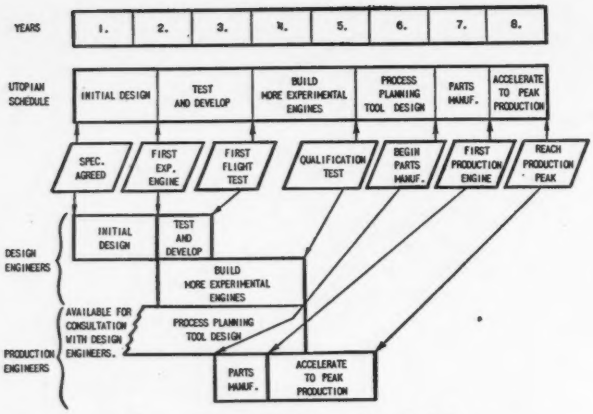


Figure 5. The telescoped schedule.

experience, much time can be saved by adopting a telescoped schedule as that illustrated in Figure 5.

Having put six new models into production during the past three years, I suggest that the following steps would greatly reduce the time required to reach full production:

1. The production engineers should be readily available for consultation with the mechanical design engineers once the latter have completed their initial designs. Care should be exercised that the production engineers are not brought in before the basic design is crystallized, otherwise the functional efficiency of the engines may suffer for the sake of producibility. This remark may sound strange coming from a production man so I would like to repeat it. Care should be exercised that the production engineers are not brought in before the basic design is crystallized, otherwise the functional efficiency of the engines may suffer for the sake of producibility.
2. Preliminary drawings of all major components should be released for study by the production engineers at the earliest possible time, not later than first flight test.
3. Plans should be made to produce a number of production prototypes as far in advance of the delivery schedule as circumstances will permit. These will have to be brought up to production standard later, but I can assure you that the effort will pay handsome dividends when you are faced with a relentless delivery schedule.
4. The design engineers should be prepared to accept from the production engineers, proposals regarding changes to the called-up tolerances. Such changes are often necessary in the interest of economical manufacture and should be given the utmost consideration in view of the fact that the Manufacturing Department is operating to this telescoped schedule.
5. It is absolutely essential that a single change control authority be established to govern the introduction of all modifications and amendments.

For each of the six engines which have been put into production to date, parts manufacture commenced ahead of the qualification test. And in all cases but one, production engines were delivered in the same month that the qualification test took place. In fact for the latest engine to go into production, more than 70 engines had been built by the time the qualification test was completed.

There are also a few pitfalls that I would suggest be given a wide berth. Firstly, don't attempt to transplant an existing procedure or system operated by some other company; it will probably not survive in your own company because the conditions there will inevitably be different. Secondly, when tooling up for a new project, unless it is to build an engine under license, don't delay and confuse the tool engineers by numerous visits to see how everyone else is tackling his problems, which again will be different from yours. Also, don't under any circumstances sub-contract the process planning of parts to be made in your own plant.

I maintain that in these cases it is far better, and quicker, to concentrate all available experience in developing original thoughts and methods rather than to try and imitate someone else's operation. This way we will have progress.

If the foregoing suggestions are carried out, it should be possible to take a new jet engine from drawing board to peak production in about five years, providing that there are sufficient design hours available to complete the design within the telescoped schedule.

In the case of the Orenda, despite the problems of establishing a new industry which I mentioned earlier, peak production was reached within seven years. This included the introduction of two new models. Now that the industry has been firmly established, I know that we can greatly improve on this time, and that five years is not impossible to achieve.

CONCEPTION OF THE PRODUCTION FACILITIES

In our early ignorance we thought that the design of the later experimental engines would be "frozen" for production purposes. In fact the first batch of production prototypes were referred to as the "Birdseye" engines, to indicate their frozen state. Fortunately, during our pilot plant days we learned that such a state was

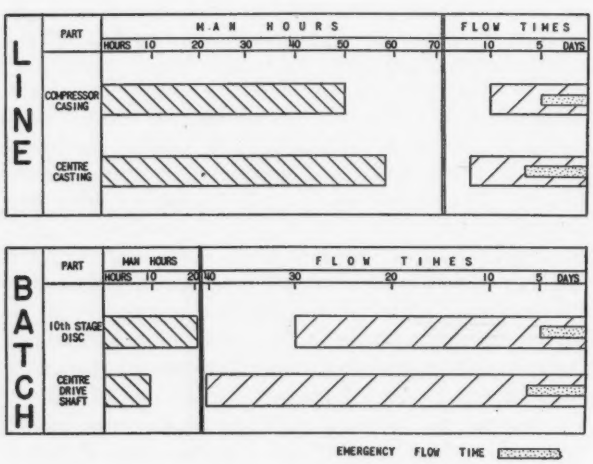


Figure 6. Line vs. Batch.

impossible, and that jet engines must be constantly modified for improved performance. We were thus well prepared for the tasks ahead.

In the light of this newly acquired knowledge we set about preparing the layout of the new plant, and ordering the additional machine tools necessary to achieve the greatly increased production expected from it. Not knowing exactly what we would be getting into, we decided to set up the plant with the maximum amount of flexibility, and the capacity to reach the target production rate.

The big question at this time was, which parts should be tooled up on a "Line" production basis and which on a "Batch" basis? Before the question could be answered satisfactorily many hours of estimating and discussion took place, the outcome of which was that with few exceptions the larger parts were tooled up on a "Line" basis and the smaller ones on "Batch", Figure 6.

The reason for using "Line" production methods for the larger parts such as compressor casings, intake castings etc. were as follows:—

(a) The flow time through the shop could be drastically shortened, thus reducing the volume of work in process and allowing for the faster incorporation of design changes.

(b) It would be easier to maintain the close tolerances required, when the large fixtures were permanently set up on the machines.

(c) The requirement of capable set-up men would be greatly reduced. This was a very big problem at that time.

(d) Movement of the larger jigs and fixtures would be eliminated except for breakdown. Some of these fixtures weigh almost 3 tons, so you can imagine the problems involved in moving such large jigs and fixtures on a "Batch" basis.

(e) Transportation of raw materials and semi-finished parts would be greatly reduced, due to the proximity of the machines.

(f) Storage space required for work in process would be much less.

(g) The volume of paperwork is much lower on line operations.

In general a part would be set up on a "Line" basis if the machine utilization on the majority of the operations was sufficient to warrant reserving those machines for the exclusive manufacture of the one part.

For the smaller items, such as shafts and drums, which require fewer man hours to complete, "Batch" production was set up. This means more movement of material and longer flow times, but was more economical in the long run. There are inevitably a number of parts which do not lend themselves to either method. They are really too big to handle on a "Batch" basis, or would not utilize sufficient machine capacity to warrant "Line" production. Fortunately for us, many of

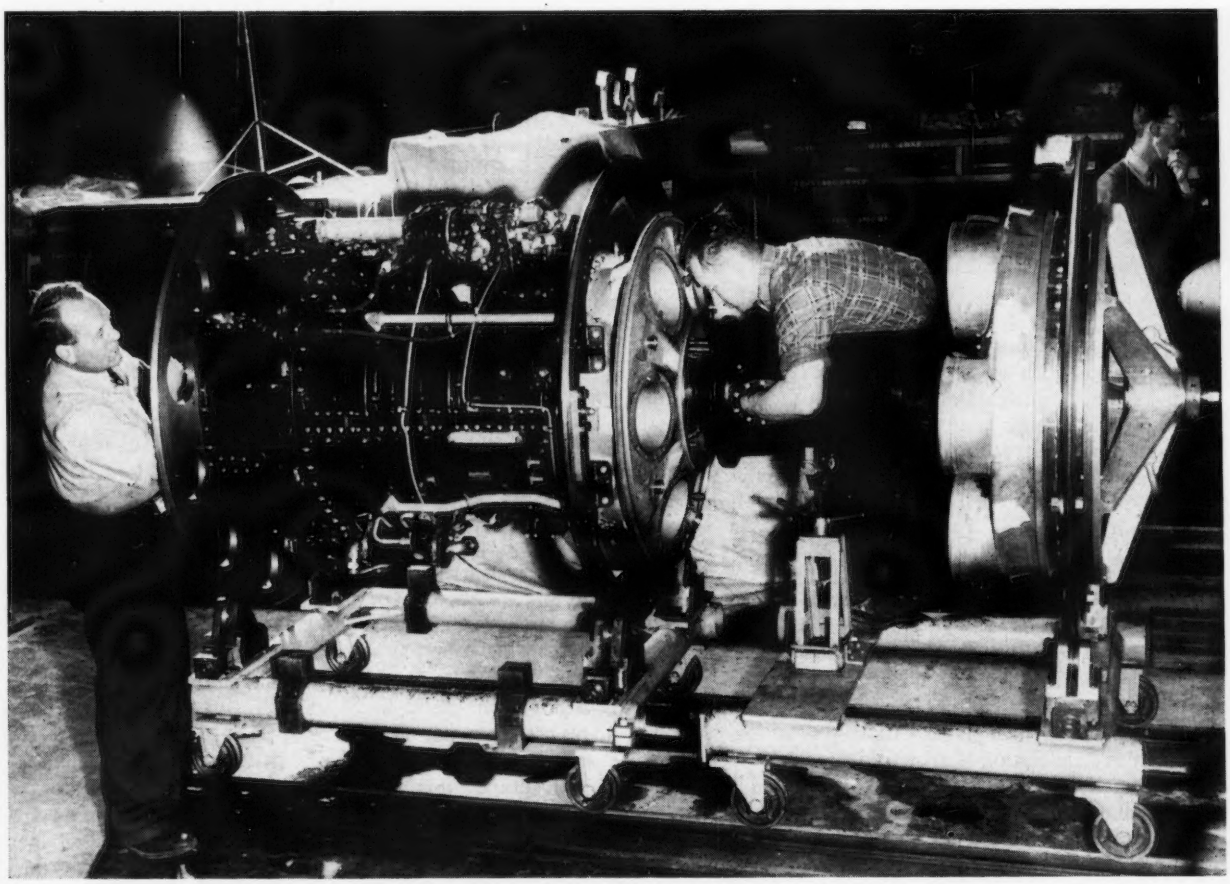


Figure 7. Horizontal build of the Orenda.

these items were very similar, such as the nine stages of aluminum discs, or the rotor and stator blades. This enabled us to set up these parts on an alternating "Line" basis, and thus reserve a number of machines for the exclusive manufacture of a number of similar parts. These machines would be set up for a few days at a time for each part.

As I mentioned earlier, flexibility was the most important requirement in the layout if progressive development of the engine was to be possible. On "Line" operation a design change to the compressor casing could be incorporated and the modified engine delivered within three weeks, if the casting was unaffected. Very few special purpose machines were used, and then only when the economic advantages were considerable. No elaborate conveyor systems were installed, more flexibility being achieved by use of a large number of jib cranes located at close intervals around the machine shop. Longer hauls were catered for by fork and utility trucks.

Great care was taken in locating the fixed installations, such as heat treat departments, test houses, tool room, shipping and receiving docks, etc. so as to avoid any relocation or inconvenience in the event of future plant expansion.

The flexibility of the plant underwent a real test in the past twelve months while producing the second thousand engines, because during this time the two stage turbine engines were introduced into production without any reduction of output.

Assembly Operation

In both the experimental and pilot plant assembly shops, all engines had been built with the use of vertical build stands; parts and sub-assemblies being brought to the stands. This meant directing the same parts to many different locations on the assembly floor. We felt that it would be much better if the assembly shop could be set up on "Line" basis similar to that used in the automotive business, having fixed build stations; the embryo engine proceeding from station to station on rail-guided build fixtures. Furthermore, we wished to avoid the expense and inflexibility of providing pits for vertical build.

To do this successfully, and also to enable the assemblers to work at ground level only, it would be much better if the engines could be built horizontally. Although the engine was not designed with horizontal build in mind, a method was devised, using a spider arrangement bolted to the nozzle box, which made possible the assembly of the engine on a horizontal basis, Figure 7.

ACCELERATING PRODUCTION

When the new production plant was officially opened, we had the plant, the equipment and the sources of supply; all that was required to complete the picture was production in the quantities needed to meet the CF-100 and Sabre airframe schedules.

At this time little information was available concerning the acceleration that should be expected, or was possible, under the circumstances in which we now found ourselves. Much data was available on airframe manufacture, and on conventional piston aircraft engines, but on jet engines – nothing – we were breaking comparatively new ground.

The whole venture at this stage was rather critical for the Canadian Aero-Engine Industry, because the Orenda, besides being the first jet engine to be built in Canada, was also the first aero engine of original Canadian design. Furthermore, it was slated to power the two key aircraft in this country's defence planning, and many millions of dollars of Government and Company money had been committed to the project.

With these thoughts in mind the process planners, tool designers, operators, assemblers, sub-contractors and design engineers concentrated their efforts on finding ways and means of increasing the production rate. No item was too large or too small to warrant attention. The factors limiting output were analyzed and rigorously attacked until overcome, at which time the next limiting item was brought under fire.

Two of the major factors to be overcome were– first, an inadequate supply of raw materials in the form of castings and forgings–and second, the speed at which tough heat-resistant steels could be cut. In the latter case much experimentation was carried out with coolants and cutting oils as these seemed to be the actual limiting factor.

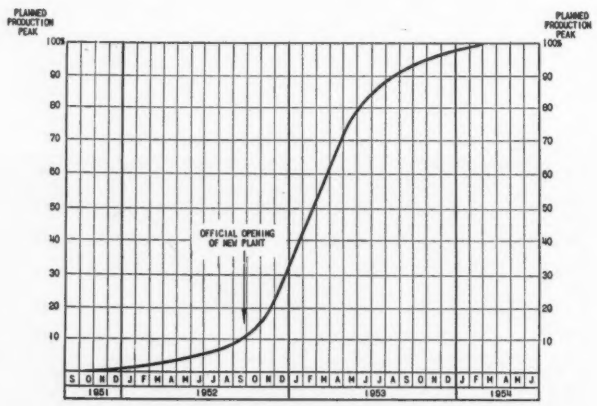


Figure 8. Production acceleration curve.

Various oils and water soluble coolants were tried, which, together with carbide tipped cutting tools of improved design, produced noticeable improvement. Then carbon dioxide was introduced on many of the turning and milling operations involving steel alloys; this allowed a further increase in cutting speeds. Continued experiments have brought us to the use of a system called Aero-mist which uses the normal shop compressed air service to atomize a combined coolant and lubricant, and blows it through a nozzle directly on to the cutting point. This has permitted greatly increased cutting speeds, much lower coolant costs, and incidentally, cleaner parts and swarf.

At the time Mr. Howe officially opened the new production plant in September 1952, we had barely reached ten per cent of our planned production peak, Figure 8. This, together with the delays in deliveries of machine tools, which meant working with temporary set-ups, made 1952 the province of the production engineer. However, once we had started on the steeper portion of this curve the industrial engineer came into his own. Time studies were made on all operations and

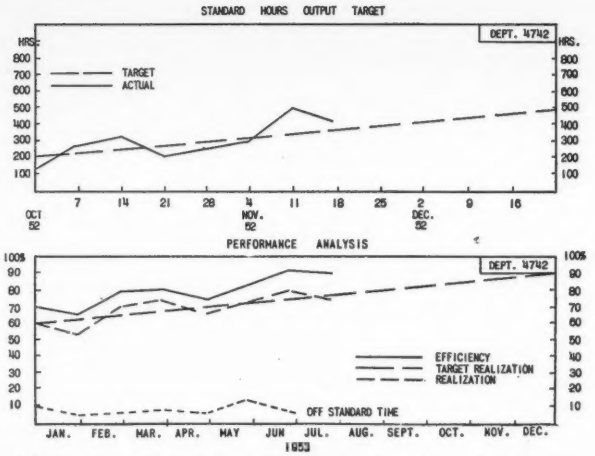


Figure 9. Production performance targets and analyses.

a system for recording off-standard time was introduced. From this information Shop Superintendents were issued with charts, Figure 9, showing the production targets for three months ahead, stated in terms of total standard hours output required. These charts were reissued each week showing the standard hours produced against target. In addition, further charts were prepared on a longer term basis indicating the standard hours realization expected and actual accomplishments, also the efficiency rating of each department. These were printed together on one chart and helped to set up a healthy state of competition between departments.

Once the volume of engines produced began to soar, new problems came to light, especially in the area of paperwork. Requisitioning finished parts from stores became a definite limiting factor, so a decision was made to adopt the concept of building the engine in the finished parts stores. This meant fencing off the whole assembly area and finished parts stores into one complete bonded area. Parts could then move freely within this area with little paperwork and only become accountable when they left the area as completed engines or on requisition for some special purpose.

THE CHANGING TARGET

So far my remarks have been mainly concerned with reaching the production target. As you well know, quantity production in itself is not enough—it must also be economical and competitive in price.

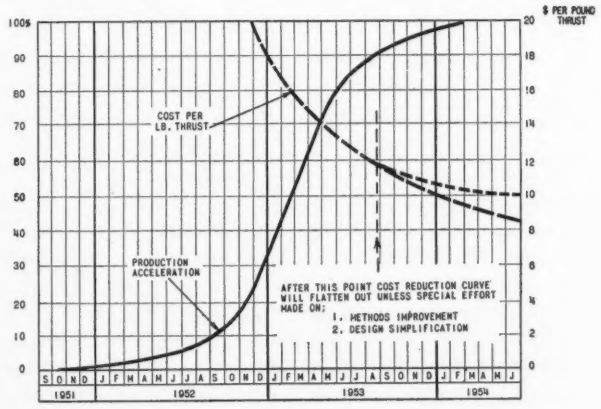


Figure 10. Cost reduction curve.

During the period of rapid acceleration on the production floor, the cost-reduction program gets a great assist due to the natural learning curve of manpower, reduced prices from sub-contractors when large quanties are ordered, and the distribution of overhead costs over a greater number of engines. However, once the production peak is almost reached, cost-reduction matters must receive ever increasing attention if the cost curve is to continue its downward path, Figure 10. It is at this stage that co-operation between the design engineer and the production engineer can again be most effective, because any further cost reductions can only be achieved by improved production methods, or design simplification for easier manufacture by both the parent plant and those of the sub-contractors. As an illustration of this point, within our plant since June 1953, sufficient manhours have been saved in the machine and assembly shops that the combined departments now spend less actual hours than did the machine shop alone at that time. Therefore, as far as manhours are concerned we now get our assembly done for free when compared with 1953. Such savings would not have been possible without considerable design simplification. Many examples of this were given in a previous paper and I would like to mention one outstanding example again. The nozzle box as it was originally released to production had to be largely machined from rough stainless steel castings and cost almost $3,000 in labour and material. Today, the redesigned box is mainly fabricated from sheet metal, is lighter, and costs less than $1,000 to produce. As a result of this and many similar cases, the cost per pound of thrust is now less than $8.00.

CONCLUSIONS

In suming up I would like to emphasize the following points:—

Develop your own talent and methods—don't become mere carbon copies of other companies.

In these days of rapid progress in technology, aero-engine manufacturers must adapt themselves to the idea of continuous development of an engine while in production.

Because of the ever present need for an engine to get into production before it is obsolete, a very high standard of co-operation is necessary between the design and production engineers.

In view of the large number of changes which production will be asked to absorb, all planning of tools and layout must have the accent on flexibility. This means that automation is not likely to hold much of value to the aero-engine industry.

However, in my opinion you can have the best plant; the best machines; and the best processes; but these are worth nothing if you have not got the best people enthusiastically working together to one common aim, and if the Orenda engine project is considered to have been successful, it is because we have, in my opinion, many such people.

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DESIGN ASPECTS OF BELL AIRCRAFT VTOL AIRPLANE†

by James A. O'Malley, Jr.*

Bell Aircraft Corporation, Buffalo

SUMMARY

The design and operation of the Bell vertical take-off and landing (VTOL) turbojet airplane are described and discussed. The aircraft is powered by two Fairchild J44 engines which are rotated from vertical attitude in hovering flight to a horizontal one in powered flight. Hovering and low speed flight control is achieved by means of compressed air jets.

As a major producer of helicopters and high speed research airplanes, Bell Aircraft is a logical company to produce the jet propelled Vertical Take-off and Landing Airplane. For years, designers and military men have been plagued by the paradox of combining very low landing speeds with very high operational speeds. In truth, it can be said that these two items are incompatible. In spite of all our efforts, runways have grown longer and longer and airplanes have been compromised more and more for take-off and landing. The jet-propelled VTOL airplane is the perfect solution for this problem in that it eliminates the necessity for runways and provides the well known supersonic capability of the jet-propelled airplane.

After three to four years study of this problem, Bell engineers became convinced that powerplants had reached the point in their development where the VTOL was practical. We felt that it would be most useful to build a small test vehicle to provide experimental verification of these findings. Since Air Force funds were not available for this purpose, Bell Aircraft financed the construction of this test vehicle. The Air Force was able to lend the company two Fairchild J44 engines, which were used for thrust, and a Continental Palouste turbocompressor which was used as a source of compressed air for the reaction controls.

SIMPLIFIED TEST VEHICLE

In starting the construction of this vehicle, we were strongly influenced by an old maxim of engineering design, *when examining a new and unconventional item, keep as many of the other items as conventional as possible.* In other words, learn to walk before you run. This is just what we did with this simplified test vehicle. Our objective was to take off vertically with jet power, to maintain a controlled hovering and to demonstrate an ability to transition from vertical flight into normal horizontal flight. We were not interested in such conventional items as high speed, or aerodynamic cleanliness at this stage of the game. As a result of this philosophy it was decided to put this airplane together from existing parts. We used a Schweitzer glider fuselage and empennage, a modified Cessna wing, a Bell helicopter landing skid, the two J-44 engines for power and the Palouste turbocompressor for a source of compressed air. The resulting airplane, shown in Figure 1, was not a thing of beauty to anyone but an engineer.

Figure 1. The Bell VTOL airplane in hovering flight.

Bell Aircraft followed the philosophy that an engineering problem requires one solution whereas an operational problem must be solved every time an airplane flies. For this reason we decided to accept some engineering problems in order to keep the airplane's attitude conventional during take off and landing. This decision required some complexity of engine mounting but did provide an airplane that (1) required no extra ground equipment; (2) had a conventional ground attitude and cockpit; (3) was able to take off and land

†Paper read before the Montreal Branch of the C.A.I. on the 11th May, 1955.

*Project Aerodynamicist.

with a transition flight path very similar to conventional flight; and (4) required no intermixing of control sense by the pilot.

We were interested in a rotating thrust vector, that is, some way to move the thrust from vertical to horizontal. If we had been concerned about high speed on this vehicle, we might have left the engines horizontal and used a rotating tail pipe bend. This would have imposed certain indeterminate losses on the thrust and would have presented a fairly complicated design problem. In the interest of simplicity, which you will recall was of prime consideration in this experiment, we did the obvious and rotated the whole engine. This procedure left the engine virtually untouched and maximized our thrust source.

STABILITY AND CONTROL

One of our major problem areas was stability and control during hovering and very low speed forward flight. It is quite apparent that normal aerodynamic damping forces do not exist on a hovering airplane. In addition, since there is no flow over the airplane control surfaces, there is no control in the ordinary sense. Our approach was based upon developing a source of control power which would be independent of speed and capable of controlling the vehicle in hovering flight. After extensive studies, we decided upon a reaction control which would be powered with high pressure air. Laboratory experiments indicated that a simple nozzle could be developed which would provide a sizeable force which could be varied in size and direction. The requirement for this control was pinned down as a result of a series of extensive stability and control analyses. Preliminary analyses indicated that the airplane would be neutral in hovering but would be strongly influenced by engine gyroscopic terms. In the interest of simplicity we wanted to make this airplane manually controlled. We did not want any artificial stabilization or control components which would be placed between the pilot and his aircraft.

This was a problem which required full consideration of the characteristics of the pilot, the airplane and the control system. We were unable to write an equation for the pilot so we decided to use him as a component in the loop of an electronic analogue computer. Fortunately we had the Reeves machines available at Bell. We built a crude stick and rudder pedal system and arranged a presentation of the aircraft attitude-velocity characteristics on a series of oscilloscopes. We connected the controls to potentiometers in such a way that we could feed various amounts of reaction control force into the circuit. The airframe equations were placed on two Reeves machines which were interconnected to account for the coupling effects of the engine gyroscopic terms. In this arrangement, the pilot was able to observe the airplane attitude on his presentation and manipulate the control to stabilize it. At the same time, it was possible to superimpose gusts on the airframe, change the control available, the gradient of control and significant parameters such as airplane weight and inertia. During the tests, two 6 channel recorders were used to make a record of pilot input, airplane attitude and velocity.

Figure 2. Ground test of reaction controls.

These records were then analyzed to define the magnitude and gradient of control force required. It was concluded that the pilot would be able to manually control the vehicle and he has since demonstrated this capability in free flight.

CONSTRUCTION AND TESTING

The airplane was built with the same simplicity as the ruling factor. Wooden fixtures were used to expedite the construction. Some test work was necessary to clear the J-44 engines for vertical operation. They were not available when the airframe was completed. In order to utilize this time in test work, the Palouste turbocompressor was mounted on the airplane and connected to the reaction control nozzles. Ground tests were performed to evaluate the installed thrust of the reaction controls on the airplane. A simplified ground rig was arranged to provide some pilot familiarization with these controls. The airplane was mounted on a semi-sphere of steel (Figure 2) and the pilot was able to apply pitch, roll and yawing moments to the airframe. The sphere provided a base for the resulting motions of the airplane. These tests built the pilot confidence in the reaction system.

When the engines arrived, additional ground tests were conducted over a pit to determine proper engine operating conditions and to establish structural heating effects. It was soon determined that structural heating was not a serious problem and that the engines could be operated vertically. The next series of tests were directed toward operating the engines from a flat plate surface. The airplane was hoisted above a steel plate and the jets were allowed to impinge directly on the surface. It was determined that a landing gear extension of one foot would provide a satisfactory operating condition, since the impingement of the jet blast moved out and away from the airplane in a thin layer. This gear modification was incorporated and all future operations were conducted from a small steel plate.

In order to give a maximum of safety in his first attempts at manual control, and to relieve the additional problem of throttle control, the pilot tested the airplane while it was partially supported by a weighted cable

arrangement. This arrangement permitted him to take off at less than full throttle and as he rose to a predetermined altitude the weight pan would contact the ground. This gave him an artificial ceiling and provided a supporting action in case of rapid decrease in power. After several flights on the cable he adequately demonstrated his ability to control the airplane and free flight was started.

On the first flight the pilot, Dave Howe, required about 40 seconds of familiarization before he was able to rise in a hovering and stabilized condition. His learning process was exceptionally fast. After about two flights of 30 to 40 seconds duration he was the absolute master of the vehicle. This was most encouraging since Dave Howe was not a helicopter pilot. After about 5 more flights it was possible for the pilot to hover the airplane for as long as 2½ to 3 minutes in one spot. This was a considerably longer period of time than it was expected would be used in a normal VTOL airplane operation.

The next series of tests included forward translation. Initially it was judged to be advisable to make this translation without rotating the engines. A forward thrust component was obtained by pitching the airplane nose down a few degrees. These tests progressed rapidly from 10 feet to 140 feet and finally to runs from one flat plate on the runway to another spot 1000 feet away. The pilot effected this translation at an altitude of about 40 feet and reached speeds of 40 miles per hour. He demonstrated his ability to decelerate to hovering, turn 180° and return to the original site without landing.

In order to provide the pilot with a running landing gear which would permit level flight landings in the event of engine failure at high speeds, a Cessna gear was modified to replace the Bell skid gear. Some taxi tests have been conducted to establish the characteristics of the running gear and the airplane has been flown in level flight to establish that flight regime. Up to the present time this has been an extremely successful flight program. The test vehicle has been shown to have the capability of hovering, translating at speeds required for transition and of flying as an airplane. To the engineers at Bell Aircraft this is the complete proof of the theoretical principle. The capabilities of the helicopter and the jet airplane have finally been wedded.

AIRPORTS' REVENUES AND TRAFFIC

by Dr. A. Jaworski

Air Transport Board

It is interesting to note that although the capital investment at the airports exceeds at least three times the investment of the airlines, relatively very little is published about the airports' financial operations. The only text book[1] on the subject is by Professor L. L. Bollinger and Associates, but it appeared in 1946 and, therefore, it contains data from the previous decade.[a]

Recently, I have tried to make a brief survey of the airport charges in Canada, and a graphical analysis of the airports' revenues and expenses during the last five fiscal years: 1949/50 - 1953/54, has shown that in average an airport requires a yearly revenue of an order of $130,000, for a breakeven point on maintenance expenses, excluding depreciation.[2]

When the ratio of airport revenues and maintenance cash expenses is related to passenger traffic – as may be expected – a positive correlation shows up. For the fiscal year 1953/54, the figures are presented on Figure 1.

The intersection point of the self support line indicates a traffic requirement for a breakeven point to be in an order of 66,000 passengers enplaned yearly.

It should be underlined that in the expenses there is no provision made for depreciation, and in some airports this cost item exceeds cash expenses. Very likely, even on a favourable assumption about the traffic progress, several small airports must be faced with a continuous operating deficit and, therefore, would call for financial assistance from the major airports that consequently should have an excess of revenues over expenses with some provision for depreciation accounted for.

(a) Since then, a few books have been issued on airport management, but with practically no financial operating data.

By and large, this happens in all branches of transport industry; the operating deficit of small stations must be counterbalanced by the profit-making stations which enjoy a high level of traffic density.

Not too great emphasis should be placed on the figure of 66,000 passengers on the graph, because the scattering of points around the trend line is quite apparent. For the same amount of traffic at different airports, the factors which determine the expenses and revenues, could vary considerably, such as climatic conditions that, during a severe winter, burden the airport with expenses for heating, snow removal and sanding of runways. On the revenue side there might be differences too; it may be noticed from the graph that for Victoria, although it ranks fifth in respect of traffic, the ratio of revenues and expenses is much below the average. One of the main reasons is that all scheduled passengers at Victoria are carried by DC-3 aircraft which pay in landing fees about 1/6 of the North Star fees ($3.28 vs. $19.50), although the seating capacity of the latter is only about twice of the former. An airport, therefore, which serves DC-3's only, receives in landing fees per passenger about three times less than the North Star is bringing in revenues/passenger to other airports. In relation to the Super Constellation, the difference is more striking still; DC-3's landing fees amount to about one-tenth of the Super Constellation, where its passenger capacity is about one-third of the latter.

The favourable position, i.e. close to the self-support line, of the Sydney, N.S. airport brings this point clearly out on the graph. About 55 percent of the airport's total revenues at Sydney are stemming from the trans-

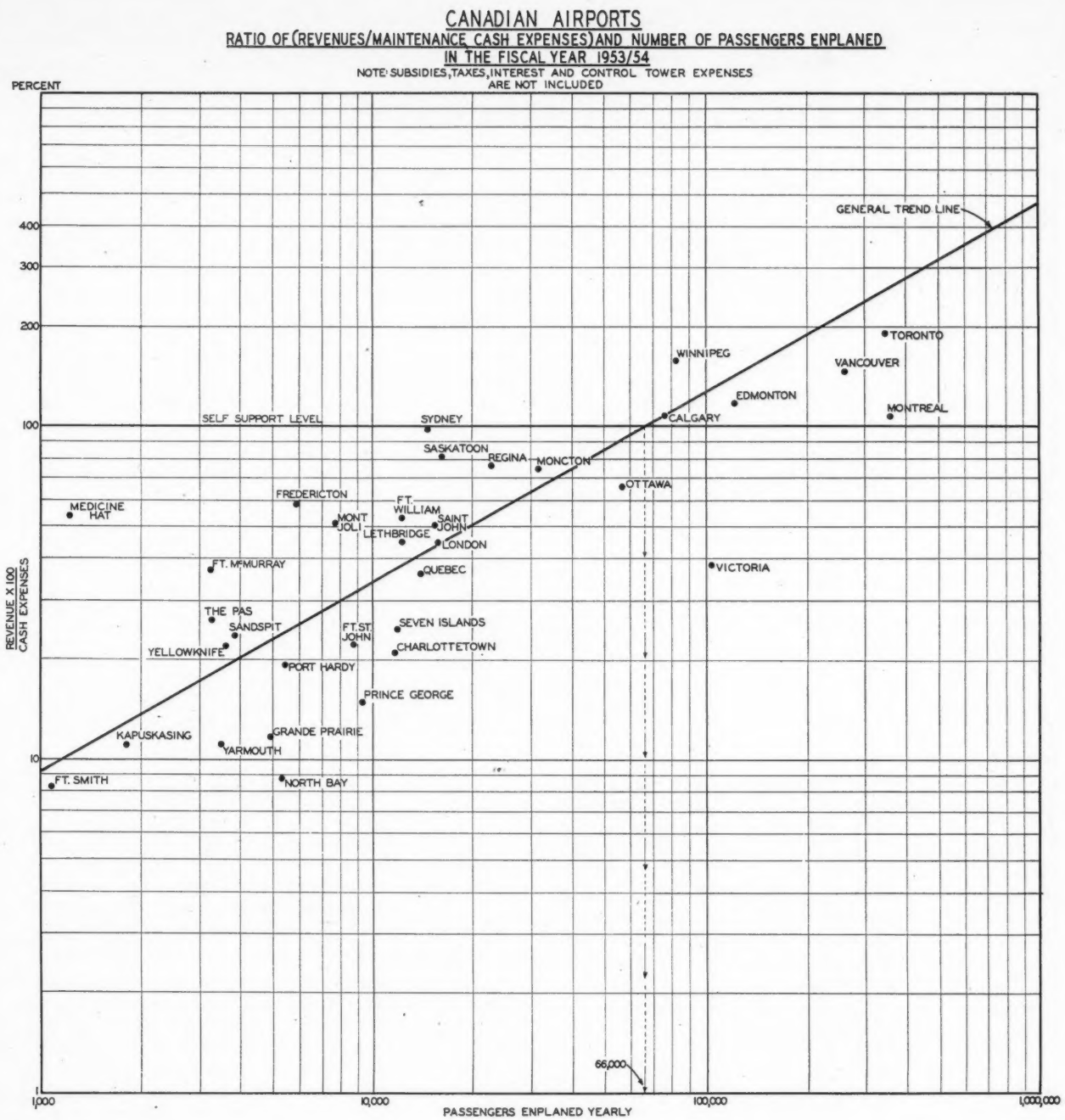

Figure 1.

Atlantic fees, and the planes on these routes are, of course, much larger than a DC-3. And last, but not least, the landing fees for trans-Atlantic flights are about 5.5 times higher than their equivalent on the domestic scale. On the average, Sydney airport is collecting for each trans-Atlantic landing about $150, against Victoria's rate of $3.28 for a DC-3.

Obviously, in several airports, some scope is left for the management to improve the ratio of revenues and expenses, especially by diminishing the expenses. And in this respect the graph may be useful, by indicating to the management other airports that are in the same bracket of traffic, or even a lower one, but are achieving a better ratio of revenues and expenses.

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TITANIUM ALLOYS FOR AIRCRAFT†

by H. V. Kinsey*

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TITANIUM is one of the newer structural metals available to the engineer and designer. We have all been made very much aware of this newcomer through both the technical and lay press. The rate of growth of the titanium industry in the U.S.A. has been phenomenal. In 1947 the annual U.S. production and world production of titanium was probably no more than a few hundred pounds. By the end of 1954 the United States was producing titanium at the rate of 7,200 tons per year and Great Britain and Japan measured their production rate in hundreds of tons per year. By the end of this year the U.S.A. hopes to be producing titanium at the rate of 13,000 tons per years and the goal in 1957 is 22,500 tons per year. By that time it is expected that Great Britain will be producing about 1,500 tons of titanium per year and that Germany will also have a titanium industry.

The reason for this phenomenal rate of growth of the titanium industry in the United States of America is that modern military aircraft development is making it necessary to use alloys that will withstand stress and strain in the temperature range of 350°F to 800°F in applications where operational temperatures were formerly limited to about 300°F.

Up to 300°F aluminum and magnesium alloys are quite adequate. Some of the newer aluminum alloys can be pushed to 400°F. However, above this temperature, some other alloy must be used. Steel, with a density three times that of aluminum, could be used at considerable weight sacrifice. However, titanium, with a density of only about one and a half times that of aluminum and strength equivalent to steel at temperatures up to about 800°F, makes it possible, in some cases, to design for operation in this temperature range without having to pay the weight penalty of steel.

In this time when high overall operational efficiency of military aircraft seems to be the goal, almost regardless of cost, the potential demand for titanium has reached major proportions for this reason.

There are certain types of applications where titanium is proving extremely useful. In the modern jet engine, with high compression ratios, temperatures as high as 700°F may be encountered in the compressor. Here titanium blading and discs offer distinct advantages in weight saving over steel. Also, many structural components of the engine and bolts can be made of titanium alloys.

The main characteristics of titanium alloys being exploited in such applications are its high strength to weight ratio in this temperature range and its low density, resulting in low stress levels in parts loaded by centrifugal force. Elastic strain is probably not too critical here.

When considering titanium alloys for structural members or skin of an airframe, due regard must be had for its relatively low modulus of elasticity (17 million psi vs 28 million psi for steel). The ratio of modulus of elasticity to density for steel, titanium, aluminum and magnesium is 10^8 in every case. This imposes some limitation on the usefulness of titanium alloys in aircraft construction.

It has been shown that in certain types of stressed structures, where column or plate buckling could be the mode of failure, titanium alloys are often the most efficient structural alloys to use between 350°F and 800°F. However, where stiffness is the criterion, an alloy steel may very well be the best alloy to use.[1]

There is no easy answer to where to use titanium alloys in aircraft construction. Each potential application must be completely analyzed for type of loading, stress distribution, operating temperature, and also fabricating and production methods. The metallurgical engineer can supply the basic data for such studies. The design and production engineers must apply this data.

COMMERCIALLY AVAILABLE ALLOYS

The development of titanium alloys from laboratory experiments to production line has been forced at a pace unheard of in any other metal and has been carried out under adverse conditions. It is not surprising that many serious deficiencies in some alloys and non-uniformity in most have been the order of the day. It is a credit to the ingenuity of metallurgical and production engineers that, in spite of these handicaps, progress is continuing.

The quality of the raw titanium (titanium sponge) has been constantly improving. Impurities found in

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titanium raise its hardness. From 1950 to 1952 the impurity content was such that the hardness of the titanium produced ranged between 180 to 200 Brinell. By 1954 this hardness figure has been reduced to between 140 to 160 Brinell and now it is possible to obtain titanium sponge having a hardness of 120 Brinell. High purity titanium produced under laboratory conditions will have a hardness of 100 Brinell.

The difficulties of trying to develop alloys for commercial production from a base material that is continually changing can be well imagined. Until recently, the effect of some impurities, specifically hydrogen, was not fully appreciated. Also the lack of knowledge of the behaviour of certain alloys after hundreds of hours exposure to elevated temperatures, before the inclusions of such alloys in production programs lead to some unforeseen component failures. However, one can be reasonably certain that most of the major short-comings are now well on the way to being either overcome or avoided. Improved metal quality makes it possible to use alloy additions more efficiently, thereby obtaining improved ductility at high tensile strengths. Improved melting and alloying techniques are gradually eliminating non-uniformity and segregation and a more complete understanding of the mechanical properties of these alloys is making it easier for the design engineer to properly assess the suitability of a titanium alloy for any specific application.

Some typical alloys that have reached the state where they are available on a commercial or semi-commercial basis are listed by chemical composition in Table 1. The mechanical (tensile) properties of these alloys as supplied either by the manufacturer or obtained from published literature, are given in Table 2.

TABLE 1
TITANIUM ALLOY COMPOSITIONS

Alloy Designation	Per Cent						
	Cr	Fe	Mo	V	Mn	Al	Sn
C–130A (AMS4908)					8		
C–130AM (AMS4925)					4	4	
Ti140A	2	2	2				
Ti155A	1.4	1.3	1.3			5	
MTS3Al–5Cr	5					3	
3Mn Complex	1	1	1	1	3		
C110AT						5	2.5

Other mechanical properties, in addition to those listed in Tables 1 to 4, that are of vital importance to the engineers are fatigue and notch sensitivity.

The fatigue limit of titanium alloys (in the unnotched condition) is reported to be between 55 per cent and 85 per cent of the tensile strength.[2] A nominal figure for steel is 50 per cent of the tensile strength and 30 per cent for aluminum alloys.

There seems to be some uncertainty about the notch sensitivity of titanium alloys. This uncertainty probably

TABLE 2
TENSILE PROPERTIES 75°F TO 800°F

Alloy Designation	Temp. °F	Tensile Strength psi	Yield Strength psi	% Elong. in 2 in.	Modulus of Elasticity psi
C–130A	75	130,000	120,000	20	15,500,000
	200	120,000	100,000	19	14,900,000
	400	105,000	77,000	17	13,500,000
	600	95,000	67,000	13	12,300,000
	800	80,000	52,000	25	11,000,000
C–130AM	75	150,000	135,000	17	16,600,000
	200	133,000	120,000	16	15,900,000
	400	120,000	105,000	15	14,800,000
	600	110,000	93,000	15	13,700,000
	800	95,000	77,000	20	12,600,000
Ti140A	75	147,000	128,000	22	
	200	131,000	107,000	23	
	400	113,000	88,000	22	
	600	100,000	73,000	19	
	800	80,000	50,000	22	
Ti155A	75	150,000	135,000	10	
	200	140,000	128,000	20	
	400	132,000	118,000	20	
	600				
	800	106,000	92,000	18	
3Mn Complex	75	180,000	170,000	15	
C110AT	75	125,000	120,000	18	
	200	105,000	95,000	19	
	400	80,000	70,000	17	
	600	70,000	55,000	17	
	800	68,000	54,000	16	
Unalloyed Titanium (Ti75)	75	95,000	80,000	27	15,800,000
	200	77,000	71,000	22	15,000,000
	400	54,000	38,000	40	13,800,000
	600	43,000	27,000	28	12,500,000

TABLE 3
CHARPY IMPACT AT ROOM TEMPERATURE

Alloy Designation	Foot Pounds
Unalloyed Titanium (Ti75)	18
C–130A	18
C–130AM	18
MTS3Al–5Cr	34
A–110AT	30

TABLE 4
CREEP AND RUPTURE PROPERTIES

Alloy Designation	Temp. °F	Stress (psi) for 1% Creep in 1000 hrs.	Stress for rupture in 1000 hrs.
Unalloyed Titanium (Ti75)	400	36,000	42,000
	800	8,000	16,000
C–130A	400	77,000	—
	800	13,000	—
C–130AM	400	—	—
	800	20,000	—
MTS3Al–5Cr	800	—	80,000
A110AT	400	51,000	62,000
	800	34,000	50,000

arises from differences in methods of assessing notch sensitivity and also differences in the amounts of oxygen, nitrogen and hydrogen present in the titanium used by different workers. For this reason, designers may find published data ultra-conservative and in some cases even misleading. However, based on published reports by Spretnak, Fontaine and Brooks[3]; Bishop, Spretnak and Fontaine[4]; Hanink[5]; and Sacks[6]; the following general observations may be made:

A. At 75°C titanium alloys possess a higher notch sensitivity than aluminum and magnesium alloys but a lower notch sensitivity than most steels.

B. Titanium alloys may be more sensitive to the severity of the notch than most steels.

C. The notch sensitivity evaluation of titanium alloys may depend on the technique employed, e.g. impact transition temperature data does not evaluate notch sensitivity in titanium in agreement with notch tensile data. In the impact test the material is notch sensitive. In the notch tensile test it is not.

One unforeseen characteristic of at least some titanium alloys was an alarming tendency to become brittle after exposure to a temperature between 300°F and 800°F. No attempt will be made here to discuss the reasons for this in detail. However, hydrogen is the most likely culprit.

It has been shown that in at least some titanium alloys the ductility, as measured by reduction in area in a tensile test, is sensitive to rate of strain when the hydrogen content is over 0.015 per cent[7 8]. It has also been shown that the amount of residual room temperature ductility in a tensile test bar after being stressed for several hundred hours at some elevated temperature (about 450°F) may vary inversely with the hydrogen content[8]. Other mechanical tests have also been devised to show the sensitivity of a titanium alloy to hydrogen embrittlement[8]. It is always much safer, however, to rely on a hydrogen determination and to specify a maximum hydrogen content of 0.010 per cent whenever this can be done.

Should a batch of titanium alloy be suspected of excess hydrogen content it can be salvaged by vacuum annealing at 1300°F to 1500°F for about twenty-four hours[8].

The damping properties of titanium alloys can have an important bearing on the successful design of such parts as compressor disks and blades in jet engines. Titanium has a low damping capacity[9]. This must be allowed for by designing additional damping capacity into the component under consideration.

Unfortunately, titanium is a particularly poor bearing metal. It will gall and seize both to another titanium surface or to other metal surfaces very easily. This problem has not yet been satisfactorily overcome. However, recent work indicates that nitriding, or a phosphate coating, holds some promise[10].

Up to this point the author has attempted in general terms to present briefly the case for titanium as a structural metal in aircraft and to offer some guidance in selecting useful and efficient applications. It cannot be emphasized too strongly that each specific case must be judged on its own. Titanium has many useful properties and careful engineering is certain to find many applications in aircraft construction where its high cost can be fully justified.

In assessing the suitability of a titanium alloy for a specific application its adaptability to existing shaping and fabricating facilities must be determined.

FORGING TITANIUM

Titanium alloys can be forged without undue difficulty, once one or two simple fundamentals governing the behaviour of titanium are understood and their significance fully appreciated.

Titanium, and most of its forgeable alloys, possess a transformation temperature range similar to that of steel. The top of this temperature range is about 1650°F and the bottom about 1200°F. To obtain a fine grained structure, necessary for good toughness, forging should commence not too far above 1650°F and should continue down to as near 1200°F as practical. This temperature range will vary with the specific alloy to be forged. Some operators find that forging below 1550°F tends to cause fracture. All are in agreement that excessive temperatures (over 1700°F) should be avoided. As much reduction as possible should be made between each re-heat and the number of re-heats should be kept to a minimum. Re-heat temperature for finishing should be within the transformation temperature range.

Titanium absorbs oxygen when hot and does this more rapidly as the temperature is increased. This oxygen absorption can create a hard brittle skin on the forging. To keep this oxygen absorption to a minimum it is best to avoid excessive forging temperatures and to limit the soaking time at temperature to an absolute minimum. Salt bath heating might be useful in some cases.

Titanium alloys are somewhat sluggish in flow characteristics. They are generally comparable to 75S aluminum and require approximately the same design limitations. Titanium alloys require about the same forging capacity as 75S aluminum. Figure 1 and Table 5, reproduced from an article by E. A. Fentzlaff[11], show the recommended dimensional proportions for titanium forgings and dimensional tolerances, respectively.

FORMING

The forming of titanium and titanium alloy sheet and strip into structural components for aircraft present some unique production and design problems. Workers at North American Aviation have published some of the results of experience there with titanium that is indicative of the type of problems encountered and their solution[12 13].

The normal forming methods used are bending, press forming, drop hammer, stretch forming, shearing, piercing, blanking, and friction sawing. No attempt will be made to discuss each of these in detail. Titanium and titanium alloy sheet can be handled by all of these processes, within certain limitations.

All shearing-type operations are liable to produce edge cracking unless sharp tools and close blade clearances are used. Edge cracks can be removed by filing

TABLE 5

Length & Width			Die Closure		Mismatch		
Dimensions Inches	Plus and Minus	Net Wt. lbs.	Tolerance Inches Plus	Minus	Net Wt. lbs.	Normal Die	Offset Die
Up to		0–¼	0.032	0.010	0–1	0.015	0.020
6	0.032	¼–2	0.032	0.015	1–8	0.018	0.025
8	0.040	3–14	0.040	0.020	9–24	0.025	0.032
10	0.050	15–29	0.062	0.032	25–44	0.032	0.040
18	0.062	30–44	0.078	0.032	45–64	0.040	0.048
24	0.078	45–79	0.093	0.040	65–89	0.048	0.062
30	0.093	80–124	0.125	0.050	90–119	0.062	0.087
36	0.109	125–200	0.187	0.062	120–150	0.093	0.109

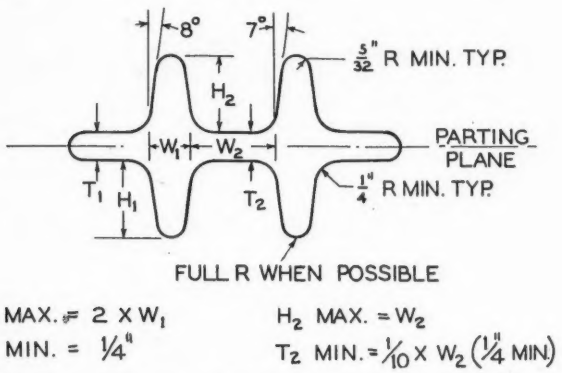

Figure 1. Recommended dimensional proportions and sectional thicknesses of titanium forgings.

and sanding. All cut edges should be de-burred prior to subsequent forming operations.

Minimum bend radius of 3T has been used for sheet under 0.070 inches thick and 4T for sheet over 0.070 inches thick. It is recommended that as large a bend radius as possible be used, preferably 4T minimum.

For long bends and for sheet over 0.050 inches thick hot bending is recommended. For unalloyed titanium, 600°F. is hot enough. For alloyed titanium the temperature should be 800°F to 1000°F. Press forming on the hydraulic press is generally more successful than on the mechanical crank type, because of its slower action.

Drop hammer forming, using ductile iron or steel dies, has proven quite successful for parts having complex contours. Blanks should be heated to 1050°F and formed hot. Drop hammer forming is characterized by a relatively large ratio of blank weight to finished part.

Stretch-forming can be used for contouring fuselage skins, and air frame components. This method is useful in making shrink flanges, which are very difficult to handle in titanium. It is sometimes possible to design tools so that the neutral stress axis is inside the piece being formed. Then all of the part is formed in tension.

Forming operations on titanium, have in the past, been handicapped by lack of uniformity, sometimes within the same piece. One remedy for this is to segregate sheet according to strength. This helps to provide a more uniform grade of material on which to standardize production techniques.

Experience has shown that components produced by forming in titanium must be held to closer dimensional and shape tolerances than those commonly maintained for stainless steel or aluminum. Proper contours and close fit up must be maintained with titanium parts because of its tendency to crack and its resistance to local deformation. This means that it is necessary to do a better job than previously required by common air frame material, when using titanium. If parts do not match it is better to use shims to take up gaps rather than attempt to force parts together in riveting.

WELDING

In general, welding is confined to unalloyed titanium. The only exception is titanium alloy C-110AT which is reported to be perfectly weldable.

Fusion welding[14 15] must be carried out under as nearly as practical perfect atmosphere protection, using either argon or helium. Small assemblies might well be made in a container under positive argon pressure. Where this is not possible, provision should be made for argon or helium protection on both sides of the seam.

Electric spot welding[16] and seam welding[17] are both readily applied to titanium, probably with less difficulty than fusion welding. A ratio of tensile strength to shear strength of about 0.3 is normal for spot welded unalloyed titanium.

For seam welding speeds range from 15 to 20 inches per minute. Hold, weld and cooling times are similar to values used for stainless steel. Close control of pressure and heat is necessary to regulate indentation and penetration and to prevent expulsion. The standard "peel test" is a quick method of determining approximate penetration.

MACHINING

The machining of titanium and its alloys has received a great deal of study. It is not the intention to cover all this detail here. However, there are some salient facts arising from these studies that might well be mentioned.

Fundamental studies of chip formation and general behaviour of titanium in machining have led to the following observations.

The low modulus of elasticity of titanium makes it necessary to hold both the work and the tool with extreme rigidity to avoid excessive chatter and vibration. This means that machine tools used for titanium should be rigidly built and in first class condition.

The chips produced when machining titanium are thinner than steel chips and are generally continuous. There is no built-up edge to the chip when titanium is being machined as there is with steel. This relatively thin chip and lack of built-up edge means that the cutting force is concentrated on a relatively smaller portion of the tool tip. This results in higher temperatures and higher rates of wear. It has been found that tool tip temperatures are relatively more sensitive to speed and feed rates with carbide tipped tools than with high speed steel. In spite of this it has been found that

TABLE 6

TOOL DESIGN FOR TITANIUM

	Back rake angle	Side rake angle	End relief angle	Side relief angle	End cutting edge	Side cutting edge	Nose radius
HSS — Lathe	0	24	6	6	6	15	0.010
Carbide — Lathe	0	6	10	10	5	45	0.015
HSS — Shaper	0	28	6	6	6	15	0.030

with proper coolants[18] and the proper geometry of the tool tip, that tool life, rates of metal removal, and power requirements, are of about the same order of magnitude for titanium alloys as for 1045 steel.

Typical successful tool designs for various cutting operations are shown in Table 6 and Figure 2.

For milling, one authority[19] recommends a carbide grade similar to Carboloy 883 at a feed of 0.003 i.p.t. in a climb milling operation, i.e., work below centre line of cutter. Dry milling is recommended with a 0° rake angle and a 45° lead angle.

Detailed information has also been published on broaching[20], reaming[21], sawing[21], drilling[21] and tapping[21].

All these machining operations can be performed satisfactorily. When the tools are sharp and the work rigidly supported, work hardening of the cut surface is extremely superficial and the degree of hardening less than that encountered in steel.

By way of summary, it might be said that the machining of titanium requires first class machine shop equipment and shop practices adapted specifically for titanium. The basic information is readily available. Titanium machining will probably tolerate less laxity in procedural control than the more common metals. It will therefore on all these counts be more expensive to machine.

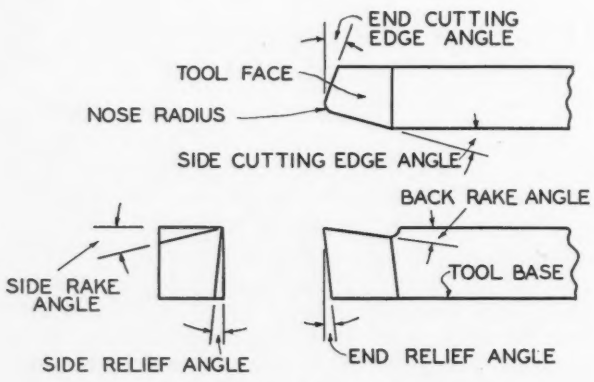

Figure 2. Typical tool angle identification.

It has been the aim of this article to present, in general terms, a fair picture of the factors that must be considered when undertaking the design and production study of titanium components, for aircraft or any other end use. Titanium is a metal unfamiliar to most of us. To be successfully used it must be judged on its own merits and not merely as a substitute for some other metal such as steel in a component designed for steel. Also proper shop practice must be set up specifically for titanium and shop equipment should be first class. Any attempt to work with titanium as though it were "just another alloy" will probably be doomed before it starts. The cost of rejects from faulty or careless shop practice can be exorbitant.

However, when titanium is approached as a new metal, having specific characteristic properties, and this approach is carried through from the drafting board, through the shop, to the finished article, experience has shown that, particularly in aircraft, there are certain applications where the cost of using titanium can be fully justified.

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THE NATURE AND STIFFNESS OF SWEPT WING DEFORMATIONS WITH REFERENCE TO THE PREDICTION OF NORMAL MODES AND FREQUENCIES†

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1.0 INTRODUCTION

THE development of methods for the aeroelastic analysis of swept wings must, as in the case of wings without sweep, lead to practical measures for the analysis of prescribed configurations, and equally important, to the provision of criteria which lay down the necessary safe and desirable conditions for the structural designer to meet.

In dealing with an existing structure, or structure for which the details have already been defined and a stress analysis produced, there is available such quantitative data as may be required for an aeroelastic analysis. The aeroelastician is in a much less favourable position, however, when he must make intelligent contributions to a design for which only a preliminary outline exists. In the latter case, the ability to predict the behaviour of generic forms or classes of wings (or in other words to lay down the design criteria) is essential.

Among the contributions to the development of design guidance for conventional unswept plan forms, there has been little to equal the simplicity and effectiveness of semi-rigid analysis. This method[1], which reduces the number of coordinates to a minimum, permits a greatly simplified study of the influence of the structural and aerodynamic parameters, and consequently it is eminently suited to the development of criteria. The general behaviour of the still air resonances serves to illustrate the chief difficulties attending such analysis, and although the material contained in this paper is of general interest, it is biased towards assessment of the practicability of semi-rigid representations. For the immediate purposes, discussion is restricted to uniform cantilevers or wings with uniform chord.

2.0 THE SPECTRUM OF RELATIVE FREQUENCIES FOR UNSWEPT CANTILEVERS

If we take as datum the fundamental flexural frequency of a uniform cantilever without sweep, then the frequencies in the ith flexural (W_{Bi}) or torsional (W_{Ti}) mode can be expressed in form

$$\frac{W_{Bi}}{W_{BI}} = \text{Const.} \tag{1a}$$

$$\frac{W_{Ti}}{W_{BI}} = \text{Const.} \times \frac{l}{d}\sqrt{\frac{GJ}{EI}} \tag{1b}$$

where l/d is the length to width ratio, and EI/GJ is the ratio of the flexural to torsional rigidity.

For rectangular profiles with depth h, we can write approximately,

$$R = \frac{EI}{GJ} = \frac{5}{8}\left(\frac{h}{d}+1\right) \tag{2}$$

so it is possible to see in a general way, the relation between the co-existent frequencies of Equations (1a) and (1b).

The relation is shown graphically in Fig. 1 where it will be seen:

(1) The flexural frequency ratios are represented by horizontal lines.

(2) The torsional frequency ratio curves are inclined to the flexural curves by an amount which depends upon the rigidity ratio.

(3) The torsional frequency ratio decreases with decrease in the ratio l/d.

(4) There are certain discrete points of intersection which represent equal flexural and torsional frequencies.

It goes without saying that near the intersection points, it would be difficult to excite one mode of oscillation without introducing the other. The likelihood of this coupling in still air decreases quickly as we remove from the intersections, but can be reintroduced by mass-unbalance, or by elastic coupling. In wings without sweep, the mass-balancing technique has been used successfully, not so much to produce complete de-coupling, as to introduce a phase relation which prohibits aerodynamically sustained oscillations. This phase angle adjustment is simplified in unswept wings due to the

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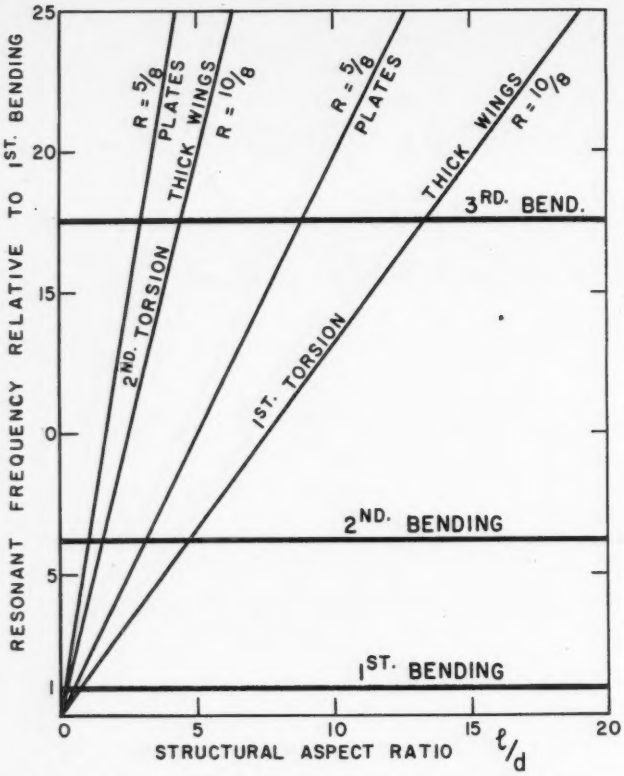

Fig. 1—Uncoupled resonances of cantilever wings without sweep.

"directional" character of the profile together with "elastic symmetry" about the elastic axis. Thus a mass moved from the trailing edge can effect a genuine reversal in phase between the coupled flexure and twist.

In elastically coupled systems, the natural phase relation between the coupled displacements is fixed, perhaps adversely, and mass-balancing therefore has less direct effect. Swept wings represent such a system and it is our purpose here to look into the general consequences under still air conditions.

3.0 THE ORIGIN OF SWEPT WING COUPLINGS

The effective coupling of displacements in a swept wing configuration is of two origins. In the first place, by inclining the wing-axis relative to the direction of flight, we obtain the same projections of displacements as would be obtained by a simple rotational transformation of the reference axes in a cantilever without sweep. In the second place, by inclining the root constraints to the wing-axis, there results a complicated system of forces and strains quite different from what would be obtained by rotation of the reference axes in a cantilever without sweep. The former effect causes most of the aerodynamic troubles, while the latter effect causes most of the structural troubles.

The basic structural effect is shown diagramatically in Fig. 2, where we consider two identical cantilever rods of finite bending and torsional stiffness, with centrelines parallel to each other but inclined to a plane through the supports. Suppose equal forces P are applied at the two free ends. Since the top flanges are in tension and the bottom flanges are in compression, the top is extended while the bottom is shortened. In elevation, looking at a plane parallel to the root plane (Fig. 2b), the two ends are rotated in the same direction. To join these two ends with a third bar (Fig. 2c) would require distortion of the bar by the forces T and A. As these forces must be supplied by the cantilevers, final equilibrium will be achieved as in Fig. 2(d) with the following results:

(a) Cantiliver AC has become more heavily loaded than BD.

(b) There is a net rotation of a line joining C to D, and

(c) The net vertical deflection of CD is reduced.

Thus, a direct force P with its line of action lying midway between C and D, is accompanied by a rotation in the plane of CD. In an equally simple way, it can be shown that a pure couple T in the plane of CD would be accompanied by a linear vertical displacement. The extent of these couplings will depend upon the relative stiffness of the components in shear, bending, and torsion.

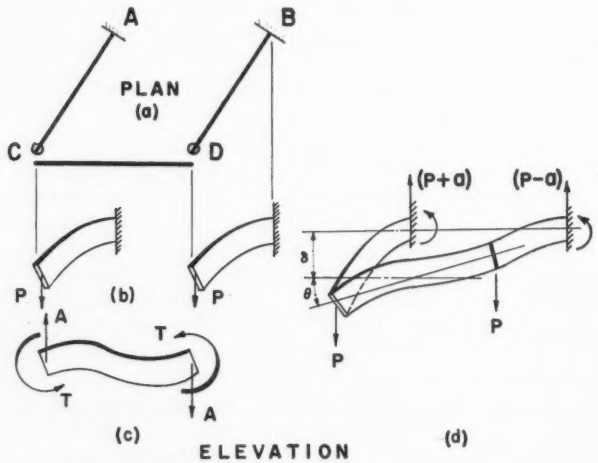

Fig. 2—Simplified basic behaviour of a "swept" structure.

While the overall behaviour of ABCD as a plate or as a stiffened shell will be essentially the same as that outlined above, the interactions throughout the plate or between elements of the shell, are more complex, and their determination requires in a particular case, considerable time and expended effort. It is therefore evident that for a general study, some simplified approach is necessary to render the flexibilities more accessible.

There is, besides the two forces P and T, a third possible direct force, namely, a couple R with its vector parallel to CD. Each of the forces will produce displacements corresponding to the direct displacements of the other two, so that in general there are nine influence (or flexibility) functions to be determined. They are defined for our purposes in Table I.

TABLE I
Influence Function Notation

	Unit Force P at y	Unit Couple T_y at y	Unit Couple R_x at y
Deflection Z at y_i	f_{Pi}	f_{Ti}	f_{Ri}
Rotation θ at y_i	F_{Pi}	F_{Ti}	F_{Ri}
Rotation α at y_i	$\mathcal{F}_{Pi}$	$\mathcal{F}_{Ti}$	$\mathcal{F}_{Ri}$

4.0 THE APPROXIMATE INFLUENCE FUNCTIONS

We would like for convenience, to interpret cantilever deformations corresponding to an arbitrary system of forces, as deflections and rotations at the reference axis Oξ (Fig. 3) which corresponds to the elastic axis of the wing without sweep. An approximate method for doing this was outlined in Ref. 2 and has been used as the basis of such calculations as were required for this paper.

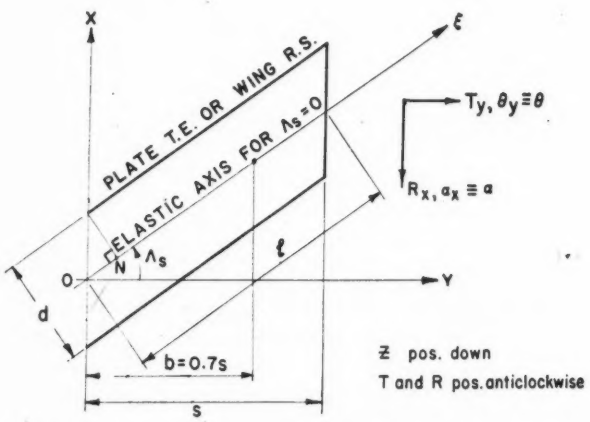

Fig. 3—Reference directions, axes and dimensions.

The approximate analysis is based on the assumption that the skewed root changes the direction of the principal strains from a direction normal to the root at O to a direction parallel to Oξ at N. To reproduce this effect, a fictitious loading is applied along ON. Outboard of N, the structure is assumed to deform as a normal cantilever. This analysis provides the necessary influence functions defined in Table I.

For convenience in summing forces and moments on complete aircraft configurations, couples are taken as pitching (T_y of Fig. 3, hereafter referred to simply as T) and rolling ($R_X \equiv R$). The rotations are $\theta_y = \theta$ and $\alpha_X = \alpha$.

In general, all of the nine influence functions are required to determine accurately the inertial forces that act on a vibrating swept beam, but there are some cases where sufficient accuracy can be achieved using only four of them. For example, in a beam with uniformly distributed mass, it has been found that the rolling inertias corresponding to the rotations α (functions $\mathcal{F}$) make very little contribution to the mode shape and frequency at least up to third resonance. For a 45° swept plate using the Z,θ coordinates (f,F flexibilities) the first three frequencies were 17.56, 85.59 and 113.8 cps. Using the Z,θ,α coordinates (f,F,$\mathcal{F}$ flexibilities) the frequencies were 17.56, 85.51 and 113.2 cps. A similar comparison for a 45° swept plate with tip mass[3] is given in Table II. It will be seen that for the fundamental and first overtone frequencies, omission of the α rotations does not lead to serious error. For the purpose of this paper, it will therefore not be necessary to employ the rotations α and functions $\mathcal{F}$. With respect to the remaining functions, comparison of the calculated curves with a set of experimental points for three stations on a 45° swept plate (36 in. x 10 in. x ⅝ in.) is shown in Fig. 4.

TABLE II
Relative Importance of Coordinate α

Length of cantilever, $l = 30$ in.
Width, d = 10 in. 00
Thickness, t = ⅝ in.
Total plate mass = .0468 $lb._w$ $sec.^2/in.$
Concentrated mass at tip = .0330 lb_w. $sec.^2/in.$
Pitching moment of inertia of mass I_θ = 6.56 lb_w. $sec.^2 in.$
Rolling moment of inertia of mass I_α = .0834 lb_w. $sec.^2 in.$
Static mass coupling S = O.

Λ_s	0°		30°		45°		60°	
Coords.	Z,θ	Z,θ,α	Z,θ	Z,θ,α	Z,θ	Z,θ,α	Z,θ	Z,θ,α
W_1 cps.	11.35	11.33	12.42	12.40	10.92	10.91	15.36	15.35
W_2 cps.	–	–	23.12	23.07	27.51	27.39	41.08	40.83
W_3 cps.	101.8	101.7	122.0	114.9	118.9	111.1	187.2	153.5

5.0 NATURE OF THE ITERATIVE VIBRATION EQUATIONS

5.1 The Use of Influence Coefficients

The value of an influence function at $y = y_i$ due to a discrete unit force P at $y = y_j$ is the influence coefficient f_{Pji}. By definition, therefore, the displacements Z_i and θ_i due to a force P and couple T at station j are

$$\begin{aligned} Z_i &= P_j f_{Pji} + T_j f_{Tji} \\ \theta_i &= P_j F_{Pji} + T_j F_{Tji} \end{aligned} \tag{3}$$

In a vibrating system, forces P and T are inertial. Dividing the wing into n segments, we obtain for the jth segment,

$$\begin{aligned} P_j &= m_j \ddot{Z}_j + S_j \ddot{\theta}_j \\ T_j &= S_j \ddot{Z}_j + I_{\theta j} \ddot{\theta}_j \end{aligned} \tag{4}$$

where S is the static mass moment about the reference axis when the moment arm is taken parallel to OX, Fig. 3. For harmonic normal oscillations, we can write

$$\begin{aligned} Z &\equiv Z \sin Wt \\ \theta &\equiv \theta \sin Wt \end{aligned} \tag{5}$$

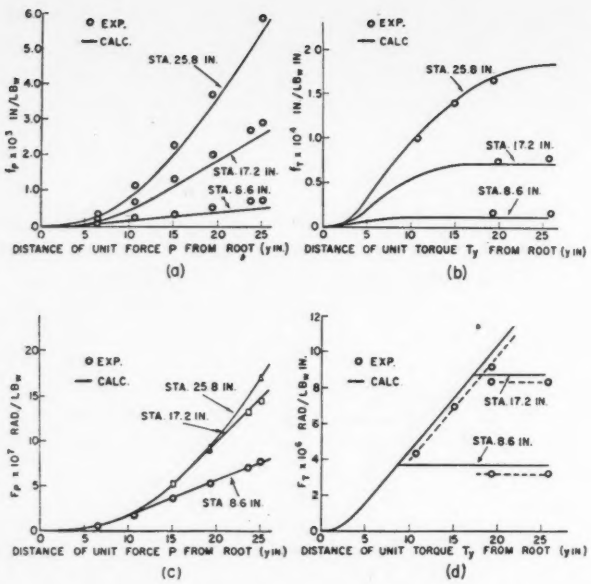

Fig. 4—Influence functions for plate with Λ_S=45°, t=⅝ in., d = 10 in., t = 36.5 in. when unit forces are moved along plate centreline.

(a) Vertical displacements due to unit force P

(b) Vertical displacements due to unit torque T_y

(c) Rotations θ due to unit force P

(d) Rotations θ due to unit torque T_y

and it is easily seen that the substitution of Equations (4) and (5) in (3) yields for the vibration amplitudes at the ith station of an n⁻ segment wing:

$$-\frac{Z_i}{W^2} = \sum_{j=1}^{n}(m_j f_{Pji} + S_j f_{Tji})Z_j + \sum_{j=1}^{n}(S_j f_{Pji} + I_j f_{Tji})\theta_j$$
$$-\frac{\theta_i}{W^2} = \sum_{j=1}^{n}(m_j F_{Pji} + S_j F_{Tji})Z_j + \sum_{j=1}^{n}(S_j F_{Pji} + I_j F_{Tji})\theta_j \qquad (6)$$

Thus there are 2n simultaneous equations. When Λ_S = O, then $f_{Tji} = F_{Pji} = O$ and we therefore see by Equations (6), that sweep has introduced terms $S_j f_{Tji} Z_j$ and $I_j f_{Tji}\theta_j$ into the deflections, and has introduced $m_j F_{Pji} Z_j$ and $S_j F_{Pji}\theta_j$ into the rotations. For a wing divided into six segments (which would be necessary to determine the fundamental mode and frequency) there would be twelve equations involving, to begin with, the computation of 144 double-term coefficients.

5.2 The Use of Influence Functions

To reduce the number of equations represented by Equations (6), the method of modal[4] or station[5] functions can be used for interpolation between a small number of reference amplitudes. By this means, the inertial forces can be obtained as continuous functions of the span, and the inertial loading can therefore be represented more correctly than by large mass segments. Solutions for the fundamental and first two overtone modes of a cantilever without sweep have been obtained[6] using only three reference stations, and the investigation of a similar solution for swept cantilevers was carried out in Ref. 7.

Thus, if the inertial force distributions corresponding to P and T are $q_P(y)$ and $q_T(y)$, we obtain in place of Equations (3) using the influence functions instead of influence coefficients,

$$Z_i = \int_0^s \left[f_{Pi}(y) q_P(y) + f_{Ti}(y) q_T(y) \right] dy \qquad (7)$$

and similarly for the rotations. The spanwise deflections and rotations are then written in terms of m reference stations Z_j and θ_j, and m polynomials $g_j(y)$, $h_j(y)$ chosen to satisfy the necessary boundary conditions. Hence,

$$Z(y) = \sum_{j=1}^{m} g_j(y) Z_j$$
$$\theta(y) = \sum_{j=1}^{m} h_j(y)\theta_j \qquad (8)$$

Corresponding to Equation (4) we then have

$$q_P(y) = m(y)\ddot{Z}(y) + S(y)\ddot{\theta}(y) \qquad (9)$$

and similarly for q_T, so that by (7), (8) and (9), 2m equations of the form (6) are obtained where m≪n.

Compared to the influence coefficient method, which requires twelve equations for the fundamental mode and frequency, station functions provide a fair approximation up to the second overtone with only six equations.

5.3 The Semi-Rigid Method

The semi-rigid method of analysis proceeds on the assumption of invariant modes of deformation, and therefore only one coordinate is necessary to define a complete mode. For two coupled modes, two coordinates or one coordinate and the amplitude ratio are necessary. For swept wings, the amplitude ratio cannot be assumed, so the semi-rigid equations in terms of the displacements and equivalent forces at the reference station (mid-aileron or 0.7 span position) take the form of Equation (6), namely,

$$\begin{bmatrix} Z_R \\ \theta_R \end{bmatrix} = -W^2 \begin{bmatrix} M_R f_{PR} + S_R f_{TR} & S_R f_{PR} + I_R f_{TR} \\ M_R F_{PR} + S_R F_{TR} & S_R F_{PR} + I_R F_{TR} \end{bmatrix} \begin{bmatrix} Z_R \\ \theta_R \end{bmatrix} \qquad (10)$$

To determine the inertial coefficients M_R, S_R and I_R, we must introduce[1] as known quantities, the modes associated with the particular resonance to be investigated. Thus, for wings with uniform chord, the inertial coefficients relative to 0.7 span will be,

$$M_R = 0.7M \int_0^{1.428} f^2(\eta)d\eta + \Sigma M_k f^2(\eta_k) \qquad (11a)$$

$$S_R = 0.7M\bar{x} \int_0^{1.428} f(\eta)F(\eta)d\eta + \Sigma M_k \bar{x}_k f(\eta_k)F(\eta_k) \qquad (11b)$$

$$I_R = 0.7M\eta^2 \int_0^{1.428} F^2(\eta)d\eta + \Sigma M_k r^2_k F^2(\eta_k) \qquad (11c)$$

where $f(\eta)$ is the flexural (Z) mode and $F(\eta)$ is the rotational (θ) mode, $\eta = y/b$ being the non-dimensional span position (Fig. 3); M is the total mass of the wing and M_k is a local concentrated mass at station η_k; $\bar{x}$

and $\bar{x}_k$ are the mass moment arms about the reference axis and r and r_k are the mass radii of gyration about the reference axis (parallel to OX Fig. 3). For wings r may be taken equal to $\frac{0.296 \times \text{the chord}^s}{\cos \Lambda_s}$ and for plates $r = \frac{0.289d}{\cos \Lambda_s}$.

The accuracy of the semi-rigid method therefore depends upon the accuracy of the assumed modes, and the method can only be applied reliably to classes of systems for which modal behaviour is well understood. We shall therefore require to inspect the behaviour of swept wings in some detail.

6.0 OBSERVATIONS AND DEDUCTIONS REGARDING SWEPT WING BEHAVIOUR

6.1 Static Deformations under Tip Forces

The modes of deformation due to forces P or T at the tip are shown in Figs. 5(a,b,c,d). Fig. 5(a) shows the span-wise variation of deflection Z for the force P, and Fig. 5(b) shows the span-wise variation of rotation θ for the torque T. Figs. 5(c) and (d) show respectively the deflection Z due to a torque T and the rotation θ due to a force P.

The effective stiffening of the root is quite apparent for low aspect ratios and high angles of sweep, and it is also clear that for small angles of sweep and high aspect ratios, the effect of sweep is very slight. The first question which comes to mind, therefore, is "For what angles of sweep and beyond what aspect ratios can we assume that the skewed root has negligible effect?" This question can be answered approximately by means of the effective length,[9] that is, the length of an unswept cantilever yielding the same displacements under the applied forces as are obtained for the actual swept structure.. The effective length of course varies with the type of load, but we shall consider a couple with its vector at an angle Λ to the elastic axis of an unswept cantilever (see inset diagram, Fig. 6). A comparison of the rotations produced for the full length and for the effective length of the same cantilever with sweep, gives a direct measure of the relative stiffness which can be plotted as a function of the l/d ratio. The appropriate effective length is, by Ref. 2,

$$l_e = l - d \tan\Lambda \left[1 - \cos^2\Lambda \, \frac{1 - \frac{5}{9} \cdot \frac{R \tan^2\Lambda}{1 + R \tan^2\Lambda}}{\cos^2\Lambda + \frac{\sin^2\Lambda}{R}} \right] \qquad (12)$$

For a cantilever with given sweep and rigidity ratio R ($= EI/GJ$), the second term on the right hand side is a constant k, say, and the relative stiffness is

$$\frac{(m_\theta)_{l_e}}{(m_\theta)_l} = \frac{1}{1 - k\frac{d}{l}} \qquad (13)$$

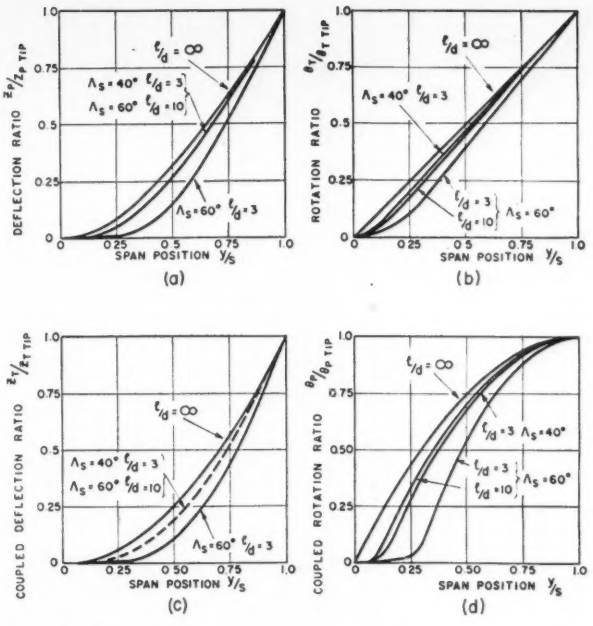

Fig. 5—Effect of sweep and aspect ratio on modes of:—

(a) Deflection due to concentrated force P at tip

(b) Rotation due to torque T_y at tip

(c) Deflection due to unit torque T_y at tip

(d) Rotation due to unit force P at tip

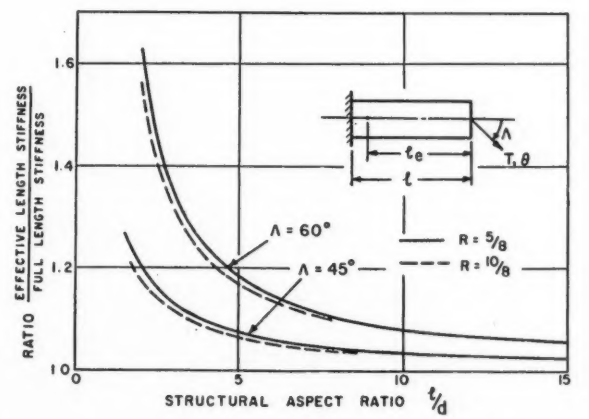

Fig. 6—Relative bending-torsion stiffness of full-length and effective-length cantilever.

The above equations lose accuracy for small values of l/d but Equation (13) has been plotted in Fig. 6 to show the approximate behaviour for two angles of sweep. It appears that the effect of the skewed root on coupled bending-torsion stiffness is appreciable for l/d around 3, but drops off to a matter of 5 to 10% for l/d around 10. It should be emphasized that the above makes reference only to the relative root effect—the stiffness $M_{\theta\Lambda}$ (corresponding to T_y, θ_y Fig. 3) in relation to $M_{\theta o}$ (T_y, θ_y for $\Lambda_s = O$) will be seen in the next section.

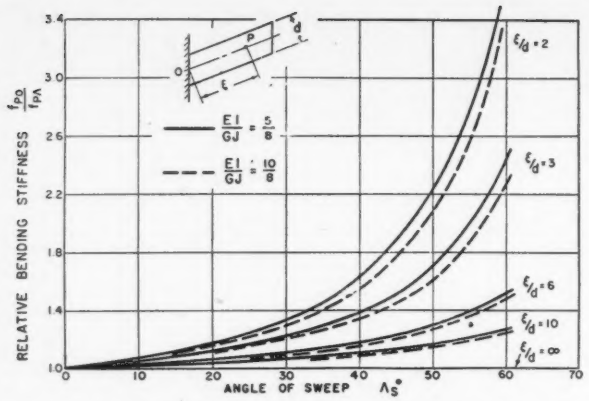

Fig. 7a—Effect of sweep, rigidity ratio, and aspect ratio on bending stiffness as indicated by influence coefficients for deflection at ξ due to P at ξ.

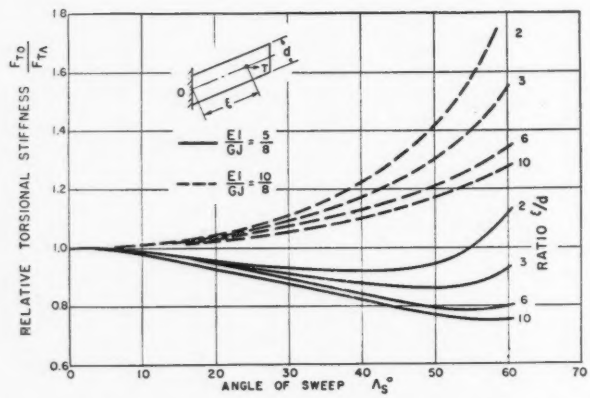

Fig. 7b—Effect of sweep, rigidity ratio and aspect ratio on rotational stiffness as indicated by influence coefficients at ξ for rotation under couple T_y at ξ.

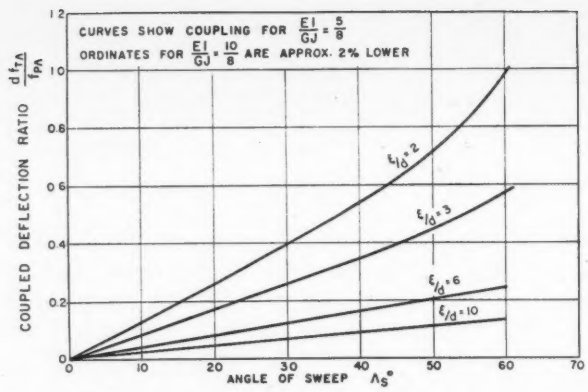
CURVES SHOW COUPLING FOR $\frac{EI}{GJ} = \frac{5}{8}$
ORDINATES FOR $\frac{EI}{GJ} = \frac{10}{8}$ ARE APPROX. 2% LOWER
COUPLED DEFLECTION RATIO $\frac{d\,f_{T\Lambda}}{f_{P\Lambda}}$
ANGLE OF SWEEP $\Lambda_S°$
$\xi/d = 2$
$\xi/d = 3$
$\xi/d = 6$
$\xi/d = 10$

Fig. 7c—Effect of sweep, aspect ratio and rigidity ratio on influence coefficient f_T (deflection at ξ due to unit torque T_y at ξ) shown at non-dimensional fraction of f_P (direct displacement at ξ due to unit force P at ξ).

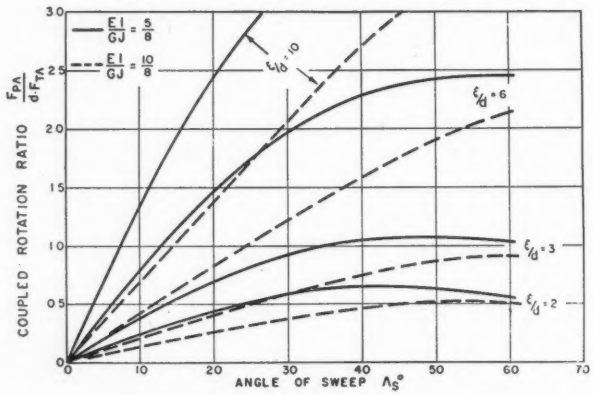

Fig. 7d—Effect of sweep, aspect ratio and rigidity ratio on rotation F_P (rotation at ξ due to unit force P at at ξ) shown as non-dimensional fraction of F_T (direct rotation at ξ due to unit torque T_y at ξ).

6.2 The Non-Dimensional Flexibilities

The flexibility (influence) coefficients of Equation (10) are the displacements at the station where the unit forces P and T are applied. Thus in Figs. 5(a,b,c,d) the displacements at the tip would be interpreted as f_{Pl}, F_{Tl}, f_{Tl} and F_P, respectively, and what we require is ready access to these coefficients when l defines a reference station and the other parameters (sweep, rigidity, aspect ratio) are known. Fig. 7, which is based on the influence functions given in Ref. 7 for plates, has been arranged to provide a usable source on the assumption that, for general purposes, the rigidity ratio R will account for a sufficient part of the rib effects.

In order to generalize the coefficients of Fig. 7, non-dimensional ratios have been computed by referring the direct flexibilities to their unswept values ($f_{Po} = \xi^3/3EI$ and $F_{To} = \xi/GJ$) and the indirect flexibilities to the corresponding direct values. This is indicated by use of the subscript Λ in reference to the swept wing, and subscript o in reference to the wing without sweep. The non-dimensional distance ξ/d is the distance ξ of the applied force from the root, in terms of the structural width d.

Assuming Fig. 7 is sufficiently representative of wings of uniform chord (it has been found satisfactory for plates and thick wing laboratory models), the flexibilities appropriate to any particular case can be obtained knowing only the angle of sweep, the structural aspect ratio, and the ratio of flexural to torsional rigidity in a plane normal to the reference axis. A guide to the estimation of the appropriate rigidity ratio of tubes with inclined ribs will be indicated presently (Section 6.3). First it is interesting to note the dynamic effect of the cross-couplings F_P and f_T.

In Fig. 8 we have two cases of spanwise mass distribution for three cantilever plates swept at 30°, 45° and 60°. For the first case, the mass distribution is uniform, while for the second case, a large mass is attached at the tip with its c.g. coinciding with the plate centre-

line. Thus, in neither case is there any out-of-balance mass, and for an unswept cantilever under these conditions, the location of the nodal lines for the resonances shown would remain unchanged.

With uniform mass distribution, the effect of sweep in the fundamental mode is to swing the nodal line towards the reference axis (plate centreline); in the first overtone the effect of sweep is to couple the first torsion and second bending modes. The addition of a mass at the tip augments both of these effects and the shifting of the nodal lines which reflects the flexural-rotational amplitude ratio, depends upon the relative magnitude of the rotational and linear inertias of the concentrated mass.

6.3 The Influence of Ribs

In the previous section it was assumed that, for general purposes, the dynamic influence of ribs could be represented sufficiently by their effect on the rigidities alone. Thus EI and GJ would become EIø and GJø where Ø is the inclination of the ribs to a plane normal to the reference axis. Actually, if the ribs are perpendicular to the leading edge, then the leading edge gains support particularly near the root, which in effect, accentuates the rotational coupling demonstrated in Fig. 2, and at the same time reduces the net vertical displacement.

An indication of the probable maximum effects likely to be derived from rib orientation was obtained by means of two built up models with uniform chord and angle of sweep 45°. The models were made from cellulose acetate, and had a 20% thickness to chord ratio, together with exceptionally stiff ribs ($I_{rib}/I_{wing} = 0.8$). In one model the ribs were parallel to the root face (direction of stream flow) and in the other they were perpendicular to the leading edge.

The fundamental and first overtone nodal lines for these two models are compared in Fig. 9 with those for the previously mentioned 45° plate. We see that when the ribs are perpendicular to the leading edge, the fundamental nodal line swings in towards the reference axis, an effect undoubtedly introduced by the additional rotation mentioned above. In the first overtone, the nodal lines near the root show a marked difference between the two models (although experimental accuracy is not too satisfactory for the small displacements in this region) but near the tip they are almost identical.

The stiffening effect of ribs inclined at an angle Ø to the normal rib-planes in a long tube, can be accounted for by rib stiffening-factors σ_B and σ_T [10] where

$$\sigma_B = \frac{EI_\phi}{EI_o} = \frac{d I_R \sin^4\phi}{\lambda I_o} \qquad (14)$$

and

$$\sigma_T = \frac{GJ_\phi}{GJ_o} = 1 + 0.22\frac{dEI_{Re}\sin^2 2\phi}{\lambda GJ_o} + .006\frac{t_R h d^3 \sin^2\phi}{\lambda J_o} \qquad (15)$$

where the subscripts o and Ø refer to the tube as a whole with ribs normal to the reference axis, and inclined, respectively, and

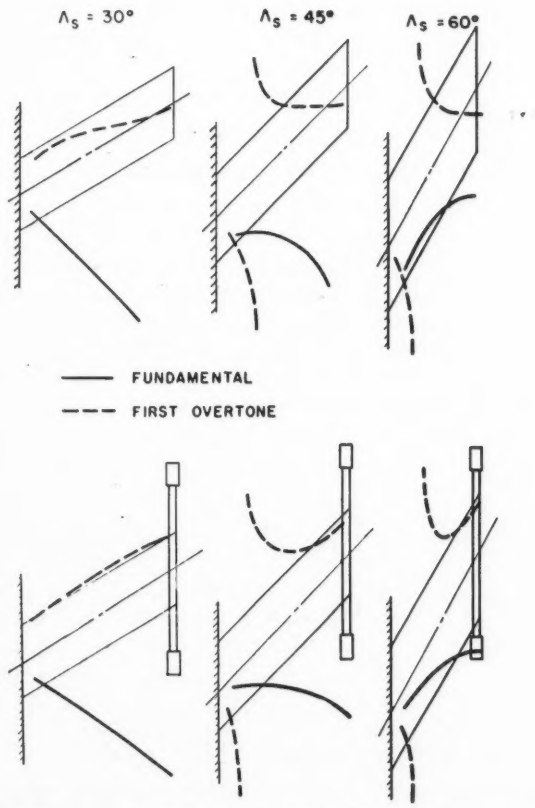

Fig. 8—Diagrams of fundamental and first overtone nodal lines for ⅝ in. plates for l/d=3 with and without tip mass.

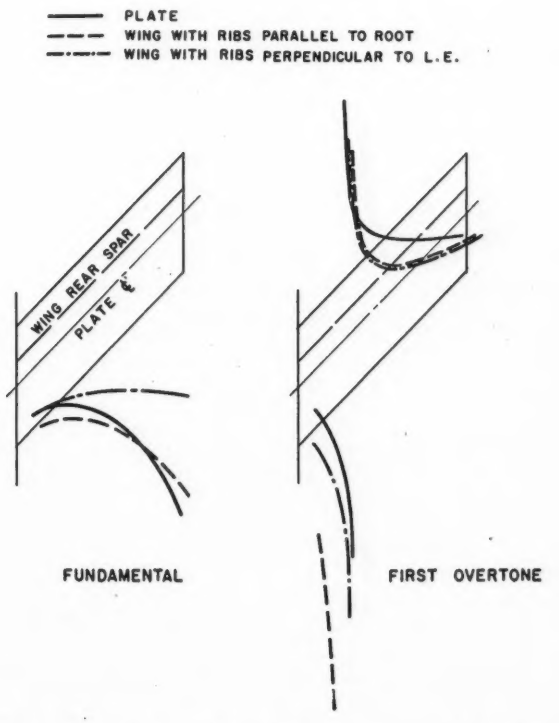

Fig. 9—Effect of rib orientation on fundamental and first overtone modes for Λ_S=45°.

$I_R = \frac{t_R h^3}{12}$ = moment of inertia (area) or rib alone

t_R = rib thickness

h = tube depth

I_{Re} = moment of inertia (area) of rib with effective width of skin

λ = rib spacing

d = tube width

$\emptyset$ = rib angle (Fig. 10)

The nature of Equations (14) and (15) is shown in Fig. 10 where they are compared with the experimental values for cellulose acetate tubes having a continuous peripheral rib to skin bonding. For swept wings with ribs parallel to the stream flow, the angle $\emptyset$ would be equal to Λ_S. The experimental points apply to the models of Fig. 9, so it appears that the stiffnesses of the two models were related by $\sigma_B = 1.12{:}1$ and $\sigma_T = 1.29{:}1$ (taking the model with ribs perpendicular to the leading edge as reference), and the rigidity ratios by $R_\phi = 0.87\frac{EI_o}{GJ_o}$.

The measured frequencies were as follows:

Ribs ⊥ l.e.	Ribs ∥ Airstream	Freq. Increase
$W_1 = 10.7$ cps.	$W_1 = 12.0$ cps.	12%
$W_2 = 50.75$ cps.	$W_2 = 62.0$	22%

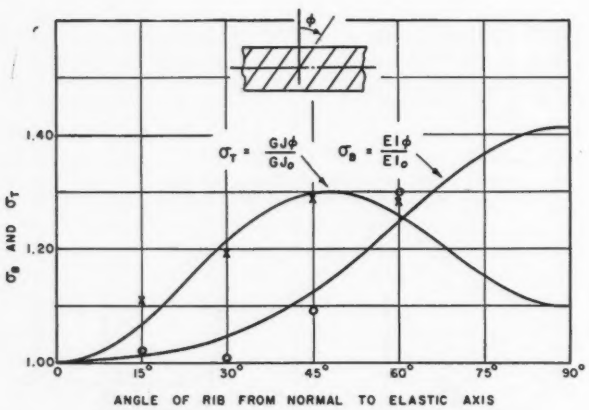

Fig. 10—Variation of rib stiffening-factors illustrated by curves for N.A.E. plastic models.

Of the percentage increases in frequencies, the rib stiffening-factors account directly for about 7% and 20% respectively in the fundamental and first overtones. Of the remainder, an undetermined part (estimated to be 2 or 3% in the fundamental) is attributable to the dynamic modulus of the material which effects a slightly greater increase when the ribs are stressed (i.e. in the inclined case) than when the ribs are not stresesd. Consequently the assumption that the overall influence of ribs can be represented sufficiently by their effect on the outboard flexural and torsional rigidities alone, appears reasonably well justified.

6.4 Vibration Modes

The coupled vibration modes for three ⅜-in. thick cantilever plates (including *l*/d ratios 3 and 3.6) are shown in Fig. 11 (fundamentals) and Fig. 12 (first overtone with 45° mode inverted for clarity). These modes were derived from results obtained experimentally and by calculation using the station function method. The calculated modes represented the effective centre-line deflections and rotations, while the experimental modes were determined from leading and trailing edge displacements. Comparison of the two results required allowance for chordwise bending and the curves shown represent the average centre-line results.

Resemblance of the fundamental modes to the diagrams in Fig. 5 is seen immediately. In the first overtone bending, the flexure loop appears to be forced outwards along the span by the root stiffening which attends increasing angle of sweep. In the first overtone rotations, the effect of sweep is very pronounced and tends to a complete modal change.

7.0 THE POSSIBILITIES OF SEMI-RIGID ANALYSIS

From the foregoing outline, it is apparent that the semi-rigid analysis would entail in addition to Fig. 7, the necessity of having a stockpile of modes appropriate to various angles of sweep and *l*/d ratios. This would mean a considerable increase over the unswept requirement in computational baggage, but there would be an incomparable decrease in the computational work involved in routine calculations.

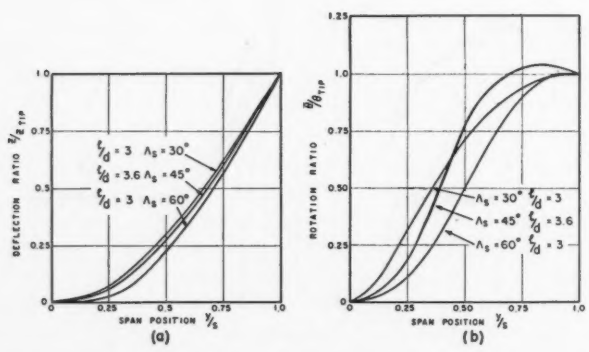
DEFLECTION RATIO z/z_{TIP}
$\ell/d = 3$ $\Lambda_S = 30°$
$\ell/d = 3.6$ $\Lambda_S = 45°$
$\ell/d = 3$ $\Lambda_S = 60°$
SPAN POSITION y/s
(a)
ROTATION RATIO θ/θ_{TIP}
$\Lambda_S = 30°$ $\ell/d = 3$
$\Lambda_S = 45°$ $\ell/d = 3.6$
$\Lambda_S = 60°$ $\ell/d = 3$
SPAN POSITION y/s
(b)

Fig. 11—Coupled bending and rotation modes in fundamental (lowest) frequency oscillation for swept plates.

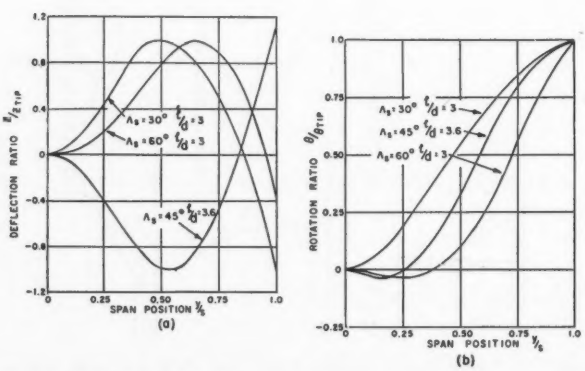
DEFLECTION RATIO z/z_{TIP}
$\Lambda_S = 30°$ $\ell/d = 3$
$\Lambda_S = 60°$ $\ell/d = 3$
$\Lambda_S = 45°$ $\ell/d = 3.6$
SPAN POSITION y/s
(a)
ROTATION RATIO θ/θ_{TIP}
$\Lambda_S = 30°$ $\ell/d = 3$
$\Lambda_S = 45°$ $\ell/d = 3.6$
$\Lambda_S = 60°$ $\ell/d = 3$
SPAN POSITION y/s
(b)

Fig. 12—Coupled bending and rotation modes in first overtone oscillation for swept plates.

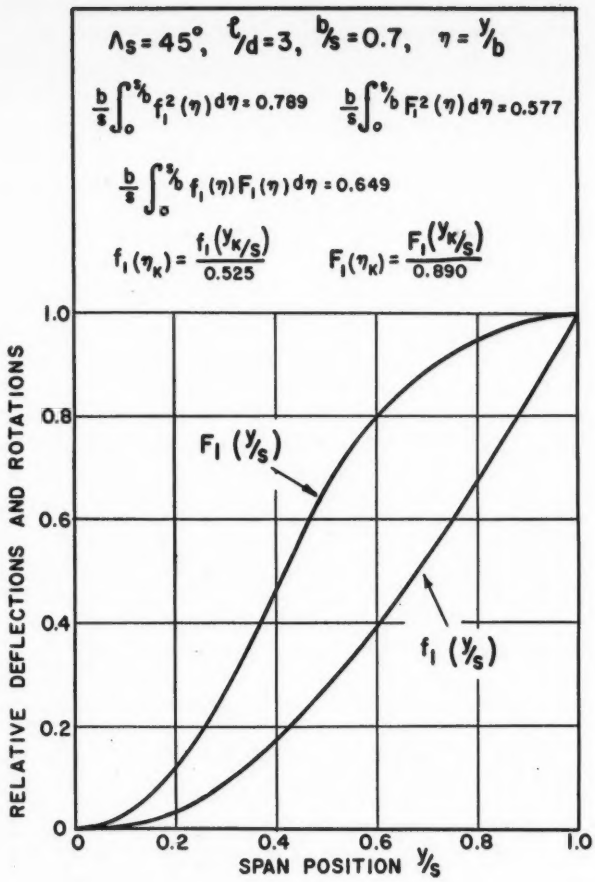

Fig. 13a—Coupled fundamental modal functions for use in semi-rigid analysis.

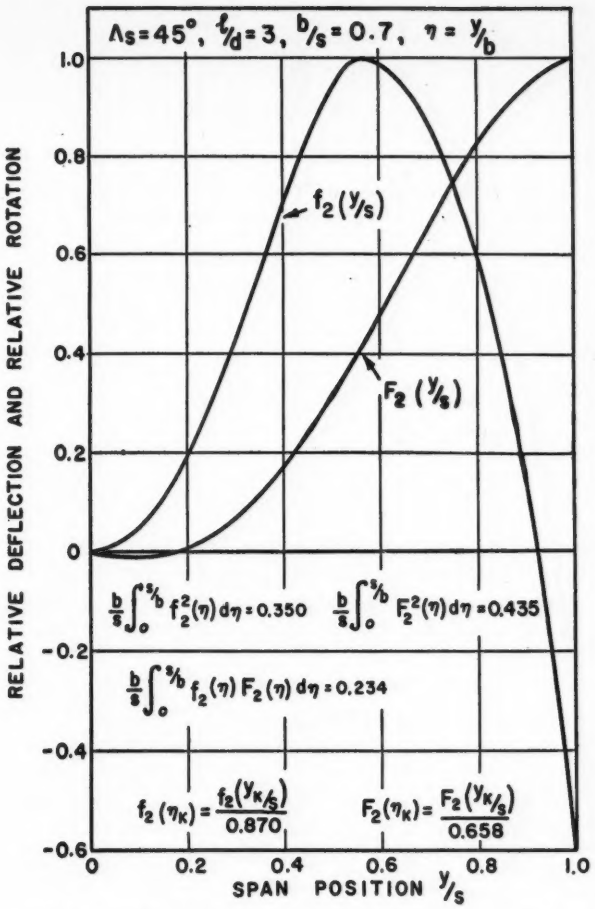

Fig. 13b—Coupled first overtone modes for use in semi-rigid analysis.

An example of the modal requirements for the fundamental and first overtone are presented in Figs. 13(a,b) for the case of $\Lambda_S = 45°$ and $l/d = 3$. Both the modal integrals and the modal ordinates are necessary in order to handle concentrated masses (see Equations (11)), and the number of such data sheets depends upon the lattitudes in sweep and aspect ratio over which acceptable accuracy is forthcoming from a single set of curves such as Fig. 13.

Equation (10) can be used immediately to obtain an indication of how sweep affects the resonant frequencies. For simplicity, let it be assumed that there are no concentrated masses and no static unbalance. In addition, the negative sign will be dropped as it is unnecessary. Then,

$$\begin{bmatrix} Z_1 \\ \theta_1 \end{bmatrix} = W_1^2 \begin{bmatrix} M_R f_{PA} & I_R f_{TA} \\ M_R F_{PA} & I_{TR} F_A \end{bmatrix} \begin{bmatrix} Z_1 \\ \theta_1 \end{bmatrix} \tag{16}$$

and the lowest (fundamental) frequency is determined by (16) when M_R and I_R are computed by Equations (11) and Fig. 13 using $f_1(\eta)$ and $F_1(\eta)$. Thus the fundamental is

$$W_1^2 = \frac{1}{M_R f_{PA}\left(1 + \frac{I_R f_{PA}}{M_R f_{PA}} \cdot X\right)} \tag{17}$$

where the amplitude ratio X is given by

$$I_R f_{TA} X^2 + (M_R f_{PA} - I_R F_{TA}) X - M_R F_{PA} = O \tag{18}$$

When $f_1(\eta)$ corresponds to the unswept cantilever, and $f_T = F_P = O$, then

$$W_{B1}^2 = \frac{1}{M_R o f_{PO}} \tag{19}$$

so it is possible to write (17) in the form

$$W_1^2 = W_{B1}^2 \left[\frac{\int_S f_{10}^2(\eta)\,d\eta}{\int_S f_{1A}^2(\eta)\,d\eta} \cdot \frac{f_{PO}}{f_{PA}} \cdot \frac{1}{\left(1 + \frac{I_R f_{TA}}{M_R f_{PA}} : X\right)} \right] \tag{20}$$

Bearing in mind the increased concavity of the modes $f(\eta)$ with sweep, and because all the quantities in Equation (20) are positive, we see that the swept frequency will be increased due to a decrease in the modal integral; it will be increased due to the increase in stiffness; and it will be decreased somewhat less directly by the degree of coupling.

The first overtone frequency (using $f_2(\eta)$ and $F_2(\eta)$ for computation of the appropriate values of M_R and I_R, say $M_R{}^1$ and $I_R{}^1$) will be given by

$$\begin{bmatrix} Z_2 \\ \theta_2 \end{bmatrix} = W_2{}^2 \begin{bmatrix} M_R{}^1 f_{PA} & I_R{}^1 f_{TA} \\ M_R{}^1 F_{PA} & I_R{}^1 F_{TA} \end{bmatrix} \begin{bmatrix} Z_2 \\ \theta_2 \end{bmatrix} \tag{21}$$

In Equation (21) we must substitute for Z_2, its value obtained from the orthogonality condition

$$Z_1{}^1 Z_2 + \theta_1{}^1 \theta_2 = O \tag{22}$$

where $Z_1{}^1$ and $\theta_1{}^1$ are the amplitudes of the transposed Equations (16). Because $Z_1{}^1$ can always be taken as unity, Equation (22) becomes

$$Z_2 = -\theta_1{}^1 \theta_2 \tag{23}$$

so we get directly,

$$W_2{}^2 = \frac{1}{(I_R{}^1 F_{TA} - M_R{}^1 F_{PA} \theta_1{}^1)}$$

From the above outline and example in Table III, it will be appreciated that the semi-rigid method permits calculation of the frequencies and amplitude ratios for swept wings very nearly as quickly as for wings without sweep.

TABLE III
Semi-Rigid Calculations Illustrated for a 45° Plate

Given: $l = 30$ in.; $s = 21.2$ in.; $d = 10$ in.; $b/s = 0.70$; $M = .04685$;
$M_k = .03375$ lb$_w$. sec.^{2}/in.; $y_k = 20.7$ in.; $S = S_k = O$;
$I_k = 6.57$ lb$_w$. sec.^{2} in.; $r^2 = 1/12 \left(\frac{10}{\cos. 45}\right)^2$ in.^{2}; $EI = 2.015 \times 10^6$;
$GJ = 2.955 \times 10^6$ lb$_w$. in.^{2}

By Eqns. 11 and Fig. 13:

$M_R = .037$; $I_R = 0.451$; $M_{Rk} = 1.117$; $I_{Rk} = 6.57$

From Fig. 7;

$$\frac{f_{Po}}{f_{PA}} = 1.79; \quad \frac{F_{To}}{F_{TA}} = 0.91; \quad \frac{d.f_{TA}}{f_{PA}} = 0.58; \quad \frac{F_{PA}}{d.F_{TA}} = 0.68$$

For a uniform cantilever:

$$f_{Po} = \frac{1 \times (0.7l)^3}{3\,EI} \text{ and } F_{To} = \frac{1 \times 0.7l}{GJ}$$

Hence for the plate:

$f_{PA} = 0.855 \times 10^{-3}$; $f_{TA} = 0.496 \times 10^{-4}$
$F_{TA} = 7.81 \times 10^{-6}$; $F_{PA} = 53.1 \times 10^{-6}$

For plate alone:

$$\begin{bmatrix} Z_1 \\ \theta_1 \end{bmatrix} = W_1{}^2 \times 10^{-5} \begin{bmatrix} 3.16 & 2.232 \\ 0.1965 & 0.3515 \end{bmatrix} \begin{bmatrix} Z_1 \\ \theta_1 \end{bmatrix} \text{ so that}$$

$$\frac{Z_1}{{}_1\theta} = \frac{1.0}{.067}, \text{ and } W_1 = \sqrt{\frac{10^5}{3.31}} = 173.7 \text{ rad./sec.} = 27.7 \text{ cps.}$$

For plate with concentrated mass:

$$\begin{bmatrix} Z_1 \\ \theta_1 \end{bmatrix} = W_1{}^2 \times 10^{-5} \begin{bmatrix} 12.7 & 34.82 \\ 0.79 & 5.48 \end{bmatrix} \begin{bmatrix} Z_1 \\ {}_1\theta \end{bmatrix} \text{ so that}$$

$$\frac{Z_1}{\theta_1} = \frac{1.0}{.079} \text{ and } W_1 = \sqrt{\frac{10^5}{15.43}} = 80.5 \text{ rad./sec.} = 12.8 \text{ cps.}$$

Measured values: 26.2 cps. and 12.1 cps. respectively.

8.0 THE SPECTRUM OF RELATIVE FREQUENCIES FOR SWEPT CANTILEVERS

It is helpful at this point to visualize the approximate influence of sweep by superimposing on Fig. 1 some of the main results discussed in the previous sections. Referring to Fig. 14, the changes in relative frequencies due to change in stiffness alone is shown by the broken lines corresponding roughly to $\Lambda_S = 60°$. For less sweep, the broken lines would fall nearer to the initial lines of Fig. 1 for $\Lambda_S = O$ (shown solid), and as the ratio l/d increases, the effect of sweep quickly dies out.

The frequency ratios now fall in regions, rather than at specific points, and the exact location, as indicated in the preceding section, is influenced by the degree of coupling. Coupling is unlikely to permit the squared frequencies to be raised in proportion to the full stiffness increase, hence the hatched regions corresponding to the fundamental and first three overtones, are shown bounded by the stiffness lines.

All modes are now coupled and the points of equal frequency in Fig. 1 are displaced. The effectiveness of mass-balancing decreases with angle of sweep and is practically impossible for high angles of sweep.

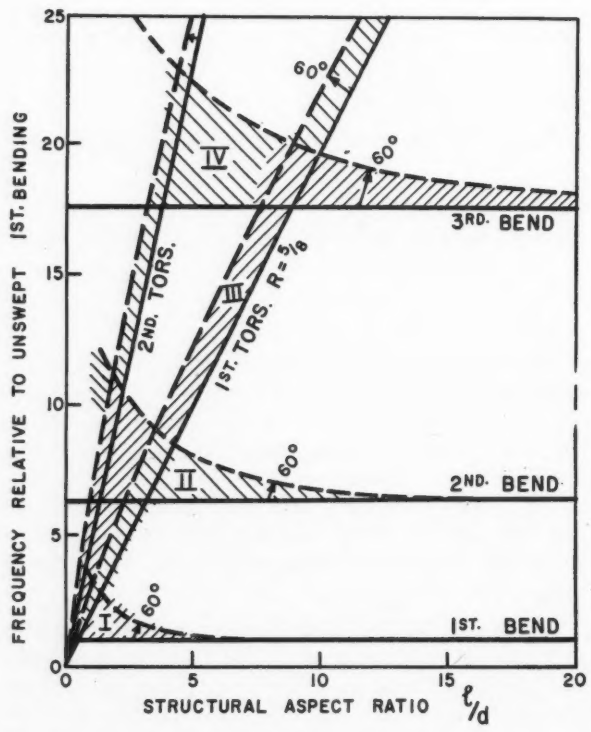

Fig. 14—Approximate effect of sweep on cantilever resonances.

9.0 THE INFLUENCE OF SWEEP ON FREE BODIES

Before concluding, it is interesting to note something about the influence of sweep on free bodies. The chief difference between swept and unswept configurations is the extent of longitudinal dynamic unbalance

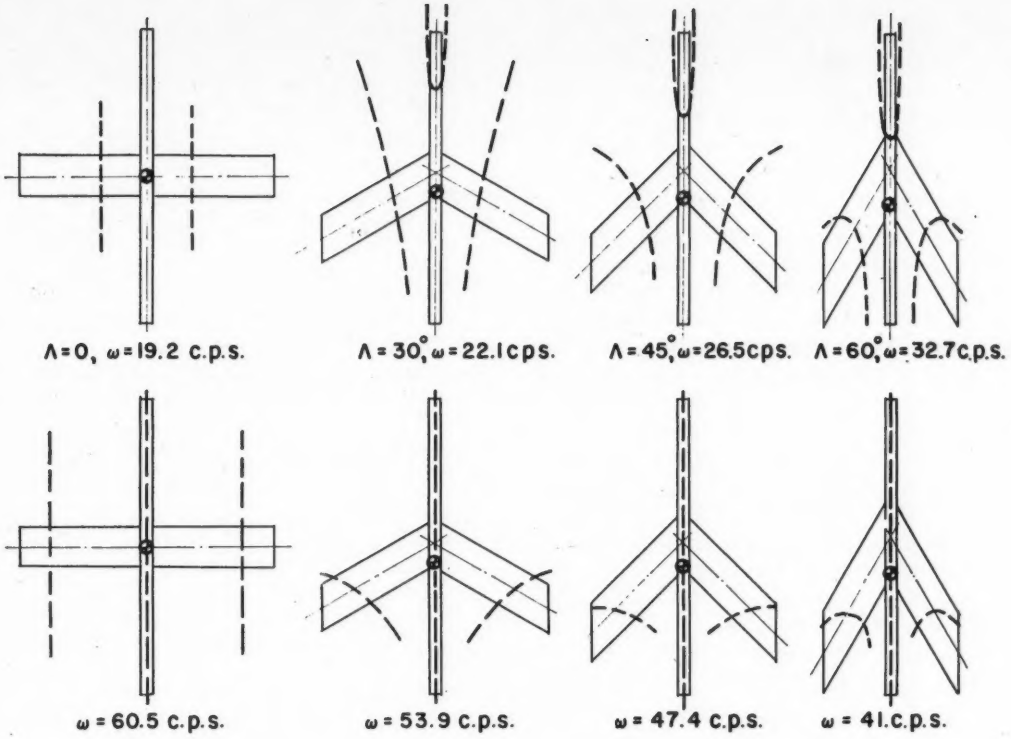

Fig. 15—Nodal lines for free-free wing-fuselage models.
Top row fundamental mode. Bottom row 1st asymmetric mode.

in the symmetric wing modes. This is demonstrated in Fig. 15 by a model with AUW 62 lb. and wing weight 26.5 lb. when the wings are swept successively from 0 through 30°, 45° and 60°. In these experiments the model was suspended by a soft elastic cord above the centre of gravity in each case.

In the fundamental (symmetric) mode, a node moves in from infinity as the wings are swept, and at $\Lambda_s = 60°$, is well within the body. At the same time, the fundamental frequency is increased from 19.2 cps. at $\Lambda_s = 0$ to 32.7 cps. at $\Lambda_s = 60°$.

Proximity of the fuselage node indicates a relatively large amplitude of pitching rotation and in a ground resonance test would call for careful consideration of the position and flexibility of suspension points.

In the first overtone (asymmetric) it appears that the original three nodal lines merge in such a fashion that the one wing nodal line reverses to follow the fuselage line to plus infinity, while the second wing nodal line follows the fuselage line to minus infinity. At the same time, the frequency is decreased from 60.5 cps. at $\Lambda_s = 0$ to 41 cps. at $\Lambda_s = 60°$. In the particular case of this model it would seem possible, with a little more sweep, to arrive at first symmetric and first asymmetric frequencies that are equal.

The addition of body freedoms to the frequency equations already discussed is a simple matter, and in the case of semi-rigid representation, presents no additional problems. However, the cantilever flexibility coefficients outlined in this paper would only hold valid for a stiff carry-through structure. In cases where the flexure and twist of the carry-through bay were significant, the effects would require to be added to the coefficients obtained from Fig. 7.

10.0 CONCLUDING REMARKS

By means of the semi-rigid equations, the associated analytic relations have been set down in their simplest form. In the time and space available, it has not been possible to examine these relations in detail, and only a few general and perhaps obvious conclusions have been drawn. In the diagrams and data provided, however, there will be found sufficient data and information to complete the examination of a number of general and particular problems.

In this outline, only brief reference was made to methods of formal analysis for the modes and frequencies. This was done chiefly to indicate the nature of the equations and the computational work associated with them, and to show the relative value of the semi-rigid analysis. To those who have only an indirect or passing interest in vibration and aeroelastic analysis, it should be again emphasized that the semi-rigid method does not supplant formal methods. It merely eliminates the necessity for determining a characteristic modal behaviour time and again, and in so doing renders more accessible those parameters over which control must eventually be exercised, namely, the stiffness and the mass and elastic couplings.

Useful as it may be in vibration analysis, the semi-rigid analysis makes an even greater contribution to the simplification of the equations of motion when aerodynamic forces are present. In view of our increased knowledge of swept wing behaviour, therefore, it was felt that now would be a good time to recapitulate the nature of the problem and to discuss at least one of the end points indicated from previous experience.

In order to be reasonably complete with the discussion as far as we have gone, it has been necessary to restrict the discussion to wings with uniform chord. None of the generality has been lost but if data in the form of Fig. 7 should prove itself adequate, then the addition of taper would be warranted and could be effected.

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C.A.I. LOG

SECRETARY'S LETTER

THE new season has begun and by the time this is printed several Branch functions will have taken place. At Headquarters we have had a fairly busy summer since the Annual General Meeting, getting under way with the new Council and the new Institute and Branch Committees, making arrangements for the I.A.S./C.A.I. meeting in November, planning material for future issues of this Journal, and preparing generally for another year's activities.

A.G.A.R.D.

The Fifth General Assembly of the Advisory Group for Aeronautical Research and Development to NATO was held in Ottawa from the 10th to the 17th June and I was fortunate enough to attend the formal Opening Session on the 15th. Dr. von Kármán was of course in the chair and the delegates were welcomed by Mr. Campney, Minister of National Defence. It was an interesting opportunity to see A.G.A.R.D. in action, "providing facilities for the exchange of information among its members" as a sort of international Aeronautical Institute.

R.Ae.S. VISITORS

Mr. N. E. Rowe, President of the R.Ae.S. and Mrs. Rowe visited Toronto on the 14th July on their return journey from the Anglo-American Conference in Los Angeles. The Toronto Branch Executive arranged an informal dinner for them at the Royal Canadian Yacht Club; our own President and I also attended with our wives. It was a very pleasant affair and Toronto Island provided a welcome relief from the rather oppressive heat of the city.

Dr. A. M. Ballantyne, Secretary of the R.Ae.S., Mrs. Ballantyne and two members of the R.Ae.S. staff, Mr. D. C. Smith and Mr. J. A. Dunsby, arrived later in the evening.

They had travelled across Canada–Dr. Ballantyne's account of the journey appears in the Editorial pages of this issue–and though they reached Toronto too late for the dinner, they were at least in time for a cup o' tea and to put in an appearance at this meeting of the two societies "at the Summit".

On greeting me at Toronto, Dr. Ballantyne's first words were "I've seen more of the C.A.I. than you have." –and I am afraid he was right.

NEW HEADQUARTERS

As this issue goes to press, we are in sight of moving into our new offices, which we have been waiting for all the summer. We hope to move during September but I would rather not say any more about it until the move is an accomplished fact.

LIST OF MEMBERS

I had intended to devote the summer months to the preliminary work on a List of Members, but the delay in moving our office has prevented me.

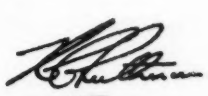
Because our present records are out of date in some respects, the List must be compiled from fresh information furnished by our members; this means that we shall have to send to each member a card to be completed (not much more than home address and company affiliation) and returned to Headquarters. In our present temporary office, with rather makeshift postal arrangements –we have to pick up our mail from the Post Office every day–we would have difficulty handling the mail which these cards would generate, and therefore we decided to postpone the whole project until our postal services were normal again.

CERTIFICATES OF MEMBERSHIP

Many members may be wondering why they have not received their Membership Certificates. Here again the delay is attributable to our office accommodation. I have a quantity of Certificates ready to be mailed but we have run out of mailing tubes. These tubes are bulky things, when procured in quantity, and we simply do not have the room to house a replenishment of the supply. So I would ask our members to be patient until we can get into our new premises.

C.A.I. LOG, No. 7

In closing, I should like to thank all those who have sent me copies of the March issue of the C.A.I. Log, in response to the notice in the last issue. I am now able to fulfil the occasional requests which I receive for complete sets of back numbers.



MEETINGS

JOINT I.A.S./C.A.I. MEETING

PLANS are well advanced for the joint I.A.S./C.A.I. meeting to be held in Ottawa on the 3rd and 4th November. The programme, in outline, appears below; a complete programme will be mailed to all members in due course.

W. Rupert Turnbull Lecture

Mr. J. H. Parkin, Director of the National Aeronautical Establishment, has been invited to present the first W. Rupert Turnbull Lecture. It will be remembered that this Lecture has been established by the C.A.I. to commemorate the important early work of the late Dr. Turnbull. It will be delivered annually at a meeting of the Institute and it is an honour to Dr. Turnbull's memory that the Institute of the Aeronautical Sciences has welcomed the suggestion that the first lecture, in this essentially Canadian series should be given at this international meeting.

Appropriately enough, Mr. Parkin has chosen as his subject a review of the pioneering work which Dr. Turnbull contributed.

Dinner Speaker

The Right Honourable C. D. Howe, Minister of Trade and Commerce, and Honorary Fellow of the Institute, has tentatively agreed to be the Principal Speaker at the Dinner associated with this meeting.

Our Guests

This will be a joint meeting, with speakers from both sides of the border, but it is being held on the C.A.I.'s home ground. A very cordial welcome is extended to members of the I.A.S.–and to their ladies, for whom a special programme is being arranged. At the first joint meeting, in October 1954, many eminent American engineers and scientists came north to visit us and we hope that even more will come this year.

Exhibits

Sustaining Members who wish to take advantage of the Meeting to arrange exhibits of their products in private rooms in the Chateau Laurier, are asked to make their own arrangements with the Hotel. A bulletin board will be provided close to the Registration Desk on which notices of such exhibits can be displayed.

JOINT I.A.S./C.A.I. MEETING

CHATEAU LAURIER, OTTAWA
3rd and 4th NOVEMBER, 1955

November 3rd	Morning	Structures	
	Afternoon	W. Rupert Turnbull Lecture	
	Evening	Dinner	
November 4th	Morning	Aircraft Safety Design and Accidents	Concurrently
		Materials and Processes	
	Afternoon	Tour of the National Aernonautical Establishment Laboratories	

The W. Rupert Turnbull Lecture
will be given by

MR. J. H. PARKIN
Director, National Aeronautical Establishment

The Principal Speaker at the Dinner will be

THE RIGHT HONOURABLE C. D. HOWE
Minister of Trade and Commerce

BRANCHES

BRANCH EXECUTIVES 1955-56

	Toronto	*Montreal*	*Ottawa*	*Vancouver*	*Winnipeg*
Chairman	W/C J. N. Bough	A/V/M A. L. James	J. L. Orr	H. D. Cameron	W. S. Haggett
Past Chairman	I. M. Hamer	E. B. Schaefer	Cdr. C. G. H. Daniel	—	—
Vice-Chairman	F. H. Keast	R. J. Conrath	G/C D. M. Holman	E. N. Atkey	J. J. Eden
Secretary	M. D. Willer	E. C. V. Norsworthy	Dr. A. Jaworski	R. J. McWilliams	R. T. Gibson
Treasurer	F. H. Buller	W. R. Cuff	R. B. Ferris		C. M. Hovey
Councillors	J. C. Floyd W. D. Hunter C. J. Luby	E. B. Schaefer R. D. Richmond	T. E. Stephenson Dr. J. J. Green*	T. W. Siers J. Bertalino	R. C. Guest D. A. Newey

*On Dr. Green's transfer to Washington, G/C K. C. MacLure has been appointed as a Councillor for Ottawa, to serve the outstanding portion of Dr. Green's term of office. Dr. Green will remain on the Council in his capacity as Past President.

BRANCH SECRETARIES

The addresses of the Branch Secretaries are as follows:—

Toronto
Mr. M. D. Willer
448 Glengrove Ave. W.,
TORONTO, Ont.
Phone—Office: CHerry 1-2651
Locals 2550-2559
Home: REdfern 9590

Montreal
Mr. E. C. V. Norsworthy
730 Upper Belmont Ave.,
WESTMOUNT, P.Q.
Phone—Office: RIverside 4-1511
Local 677
Home: DExter 4727

Ottawa
Dr. A. Jaworski,
78 Wayling Ave.,
OTTAWA 2, Ont.
Phone—Office: 9-0856
Home: 5-9751

Vancouver
Mr. R. J. McWilliams,
4243 Winnifred St.,
SOUTH BARNAY, B.C.
Phone—Office: DUpoint 1242 Local 106
Home: DExter 5764L

Winnipeg
Mr. R. T. Gibson,
P.O. Box 82, St. James,
WINNIPEG 12, Man.
Phone—Office: 6-2351 Local 31 ring 1
Home: 40-4856

SPEAKERS AND FILMS

In the next issue we hope to be in a position to give particulars of at least some of the Branch Programmes for the season.

In this connection, it is pointed out that our western Branches, at Winnipeg and Vancouver, are not very favourably placed geographically when it comes to enticing speakers to visit them. Members in Ottawa, Toronto and Montreal who have any plans for trips to Winnipeg or Vancouver and who would be willing to speak to the Branches there, are asked to write to the appropriate Branch Secretary as far in advance as possible. Alternatively, they should advise Mr. E. B. Schaefer of Canadair, who as Chairman of the National Programmes Committee, is giving what help he can to the Programmes Committees of the various Branches.

Mr. Schaefer would also be glad to hear of any good films which would be suitable for showing at C.A.I. meetings. Many companies and government establishments have produced excellent films on various facets of their work but all too frequently they treat them like technical reports, to be hidden away for the use of a few specialists. Often they would be most interesting and instructive to anyone engaged in the technical side of the business, even though they might not be directly applicable to his work.

All members are asked to bear in mind that what interests them might interest other members and, if it is not classified, to tell Mr. Schaefer about it.

NEWS

Winnipeg—Reported by R. T. Gibson

June Meeting

The newly formed Winnipeg Branch of the Canadian Aeronautical Institute held its inaugural meeting on June 21st, 1955. On that date, approximately one hundred members and guests gathered for an aircraft exhibit, dinner and a showing of aeronautical films.

Through the courtesy of the Bristol Aeroplane Company, a display of the Bristol Sycamore helicopter was arranged, giving members of the Branch an opportunity to examine this new aircraft at close range. Cancellation of the flying display was deemed necessary when severe gusting conditions presented a hazard to safe operations.

After viewing the Sycamore, the gathering adjourned to the Airport Hotel for dinner, where Mr. W. S. Haggett, Branch Chairman, presided. In his address of welcome, the Chairman outlined the history of events leading to the formation of the C.A.I. and of its Winnipeg Branch. He announced that following the inaugural meeting, there would be a summer recess, but that plans were going forward for an instructive and interesting programme for the fall season. Mr. Haggett concluded his remarks by introducing the other members of the newly elected Branch Executive Committee.

The meeting closed with a showing of the film "Fifty Years of Powered Flight", provided through the courtesy of the Shell Oil Company Limited.

Montreal—Reported by
E. C. V. Norsworthy

Golf Tournament

A concerted attack on the fairways of the Lakeshore Golf and Country Club was made in the best Service-Industry tradition on August 26th when approximately 108 members and guests competed in the Annual Montreal Branch Golf Tournament. This function, which is based on an earlier tournament originated by the Institute of Aircraft Technicians, was highly successful, the technical skill and variety of language being well up to the standard set in more

conventional Service-Industry meetings. Thanks to the generosity of a number of sustaining members and other well-wishers, the variety of prizes awarded at the subsequent dinner in the Club House was such that the athletic and arithmetical skill of the majority of members was adequately recognized, as the list of prize winners given below will testify. The sincere thanks of the entire Branch are extended to Mr. R. Conrath and Mr. J. Chadborn for their very effective work in organizing such a successful gathering.

Members

1st Low Gross	D. MacLaren
1st Low Net	H. Rhind
2nd Low Gross	E. B. Schaefer
2nd Low Net	K. Grundy
3rd Low Gross	J. Schaffer
3rd Low Net	H. A. Reid
4th Low Gross	J. Groundwater
4th Low Net	E. R. Fawcus
5th Low Gross	D. Stowell
5th Low Net	M. Escoffery
6th Low Gross	E. Higgins
6th Low Net	H. McKeown
7th Low Gross	A. J. Lilly
7th Low Net	C. L. Bernier

Guests

1st Low Gross	F/L Freidel
1st Low Net	K. Lacroix
2nd Low Gross	W/C E. Smith
2nd Low Net	W/C Edwards
3rd Low Gross	W/C MacMillan
3rd Low Net	F/L Tobin
4th Low Gross	W/C Skuce
4th Low Net	R. Marchant
5th Low Gross	S/L MacArthur
5th Low Net	J. R. Holding
No. 1 Hole Low	D. Bogdanoff
No. 3 Hole High	R. A. Neale
No. 4 Hole High	R. D. Richmond
No. 7 Hole Low	J. F. Lecavalier
No. 9 Hole High	J. O'Connor
No. 12 Hole High	A. E. Ades
No. 13 Hole High	S. Weir
High Gross	H. Whiteman
1st Attend. Prize	J. Hall
2nd Attend. Prize	J. Hutton
3rd Attend. Prize	F/L Tobin
4th Attend. Prize	C. S. Smith
5th Attend. Prize	Ted Hayes

MEMBERS

ANNUAL DUES

MEMBERS are reminded that they should pay their annual dues for the current year, 1955-56, before the 1st October 1955, if they wish to avoid the penalties incurred by being "in arrears".

NEWS

Dr. J. J. Green, F.C.A.I., Past President, has taken up his duties as Defence Research Member, Canadian Joint Staff and Senior Attaché (Defence Research) at the Canadian Embassy, Washington.

G/C R. H. Bray, A.F.C.A.I., formerly Senior Technical Staff Officer, Air Defence Command Headquarters, St. Hubert, P.Q., has been transferred to R.C.A.F. Air Division Headquarters, France.

G/C A. A. Buchanan, A.F.C.A.I., has returned from the Canadian Joint Staff in London and has been transferred to R.C.A.F. Station, St. Hubert, P.Q., where he has taken over from G/C Bray.

G/C R. C. Hawtrey, A.F.C.A.I., has been transferred from R.C.A.F. Station, Trenton, to the post of Director of Maintenance Engineering, Air Force Headquarters, Ottawa.

G/C R. M. Aldwinckle, M.C.A.I., has been appointed Director of Instrument and Electrical Engineering, Air Force Headquarters, Ottawa; he was formerly Officer Commanding, RC.A.F. T.S.D.'s at Canadair Ltd., Montreal.

W/C A. C. Bowes, M.C.A.I., has been transferred from Air Force Headquarters, Ottawa, to the R.C.A.F. Staff College, Toronto.

J. D. Finnie, M.C.A.I. of the Shell Oil Company of Canada Ltd., has been transferred by his Company from Vancouver to Toronto.

S/L W. A. Halpin, M.C.A.I., has been transferred from Ottawa to the Canadian Joint Staff in Washington, D.C.

J. M. H. Heines, M.C.A.I., formerly of Enamel & Heating Products, Amherst, N.S., has taken an appointment as a Scientific Officer at the National Research Council, Ottawa.

C. B. Jeffery, M.C.A.I., of the Gatineau Gliding Club has achieved the distinction of being the first Canadian to qualify for the Diamond Award and the International Gold 'C'. In a recent flight from Carp near Ottawa to Windsor Mills, Quebec, Mr. Jeffery established a Canadian Distance to Goal record of 196 miles.

F/L J. R. Romanow, M.C.A.I., has been transferred by the R.C.A.F. from Ottawa to the College of Aeronautics, Cranfield, England, on a two-year course.

G. Rosenthal, M.C.A.I., who was a member of the Steering Committee and Interim Council in 1953-54, has severed his connection with Canadair Ltd. and taken an appointment with Beech Aircraft Corporation, Wichita, Kans.

J. D. Koppernaes, Student, has gone to the Massachusetts Institute of Technology, on graduation from Nova Scotia Technical College.

R. W. Simpson, Student, having recently graduated from the University of Toronto, is going to the College of Aeronautics, Cranfield, England, for two years.

SUSTAINING MEMBERS

NEW SUSTAINING MEMBERS

THE following Companies have joined the Institute as Sustaining Members:

Aeroquip (Canada) Ltd.
Bristol Aero Engines Ltd.
Bristol Aero Engines (Western) Ltd.
Data Processing Associates Ltd.
Decca Navigator (Canada) Ltd.
MacDonald Bros. Aircraft Ltd.

NEWS

PSC Applied Research Ltd. announces that they have developed a high speed impulse recorder capable of recording impulses as short as 1 millisecond with 1 millisecond intervals between pulses. The record is produced on a circular piece of dry electro-sensitive paper, rotated at a pre-determined speed on a turntable similar to a phonograph recording. The recording head accommodates spring loaded styli which make their direct contact with the paper disc. When in operation, the recording head of the styli rests lightly on the rotating disc but no mark appears until power, actuated by an impulse to be recorded, is fed to an individual stylus producing a black line for the duration of the impulse. To measure the length of the impulses, a clear plastic cursor marked in time divisions is placed over the record, enabling the length of the lines made by the styli to be read.

Another piece of equipment developed by PSC Applied Research is an improved ice detector head. The improved head comprises dual probes and associated pressure switch contained in a sealed unit eliminating the usual inter-connecting pneumatic tubing and electrical cables. One of the probes is maintained at a temperature above 32°F., while the other is allowed to ice up. As soon as the icing occurs, the pressure balance between the probes is disturbed, actuating the pressure switch; heat is automatically applied to the iced probe, thus restoring normal pressure balance and the application of heat is then discontinued. In continued icing conditions, this cycle is repeated and can be used to control a de-icing system, warning lights, etc.

Field Aviation Company Ltd. is engaged in the special modification of two Canso aircraft which will be used by the Photographic Survey Corporation Ltd. and Kenting Aviation Ltd., companies associated with Field Aviation, in the British Government's Antarctic Expedition. The aircraft will be used for survey operations and will leave Oshawa in November to meet the mother ship of the expedition at Deception Island, where the aircraft will be based.

Field Aviation also announces that it has acquired the range of various aircraft parts, instruments and accessories, formerly handled by MacDonald Bros. Aircraft Ltd. Although they intend to establish their Oshawa airport base as the headquarters for the expanded business, Field Aviation will continue to distribute items from the MacDonald Bros. base at Stevenson Field, Winnipeg. Another branch will be run from Calgary airport and there will be a warehouse at Vancouver airport.

Canadian Aviation Electronics Ltd. have announced that their new Scintillometer, the CAE Airscint 1009, designed for aerial survey for radioactive minerals, is being installed by a western Canadian airline in one of its aircraft for test purposes this summer.

Minneapolis-Honeywell Regulator Company, Ltd. has established an Aeronautical Division at Leaside, Ont. The new division will operate independently of the main Aeronautical Division at Minneapolis, although it will look to the parent concern for any support it may need in serving its various Canadian customers. As a result of the establishment of this new division, Minneapolis-Honeywell aircraft control equipment will be largely manufactured in Canada in future. Mr. C. A. Anderson, formerly Assistant Director of Service Engineering of the Company's Aeronautical Division in Minneapolis, will be Manager of the new Canadian Division.

TECHNICAL FORUM

IT is proposed to devote a section of the Journal to the discussion of papers published in previous issues. This feature, which will appear in the technical part of the Journal rather than in the C.A.I. Log, will be known as "TECHNICAL FORUM".

Contributions to this section should be prepared broadly along the lines laid down in the "Instructions to Contributors" which appear elsewhere in this issue. They need not however be elaborate or long.

It is hoped that our readers will take full advantage of this "TECHNICAL FORUM", for discussion will stimulate interest and enhance the value of the original papers.

BOOKS

Canada's Flying Heritage. By FRANK H. ELLIS. University of Toronto Press. 388 pages. Illus. $7.95.

If reward in the next life is assured by tribulations in this one, the would-be historian has nothing to fear. From the moment he picks up his pen his troubles begin. If he is going to select his facts he will be accused of having an axe to grind. If he goes to the other extreme and ends up with a ten-volume work, he is pedantic and lacking in discernment. If he is so reckless as to deal with a period still within living memory of some of his readers then he invites a storm of criticism about omissions and inaccuracies.

Frank Ellis automatically puts himself up as a candidate for the treatment with his book, *Canada's Flying Heritage*. But in my opinion he deserves to get off lightly. For there is no escaping the fact that Ellis has done a job that has badly needed doing for years. And he has done it well.

His book is a painstaking record of the development of flying in Canada. Not only does he fill in the background detail on the stories of well-known men like Baldwin, McCurdy, Turnbull and Bell, but he brings some of the lesser-known pioneers into the limelight.

There are several entertaining chapters on early ballooning and airship activities in Canada and some well chronicled sections on the barnstorming days which preceded the first world war and broke out again after the war. There is some rather dutiful copy, too, on flying during the war years and on the development of air mail in Canada.

But for my money Frank Ellis is at his best when he gets sidetracked. Perhaps it is not in keeping with the approved historical technique but it does make absorbing reading—and some of his stories of the bush pilot and barnstorming days are the very essence of Canadian aviation. I particularly liked his accounts of that small band of rugged individualists, the 'early birds', who built their own planes—usually to their own design—and taught themselves to fly them. I think that these stories should be required reading for some of the new generation of pilots who think that an early bird is just another queer duck.

I liked, too, the way in which the author relates the Canadian aviation picture to the larger aeronautical scene by reference to the trans-Atlantic flights and to the many friendly invasions by American flyers on barnstorming tours or record-making attempts.

By nature of its episodic treatment the book tends to be a bit uneven at times. Certainly you are not likely to wade through its 388 pages at one sitting although the chances are that you will find yourself reluctant to put it down on many occasions. It is helped greatly by its handsome layout and its wealth of photographs and illustrations.

As a reference on the development of flying in this country, *Canada's Flying Heritage* fills a long-standing need, and its usefulness in this capacity is enhanced by the careful index and by the various appendices. Perhaps the ground has not been covered exhaustively, but if there are still blank pages to be filled—and the author himself would be the first to admit this possibility—then what better stimulus could there be than the publication of a book such as this?

To the author whose search for material covered a period of many years, to those who helped him in his task by contributing information, checking facts and even proofreading the manuscript, to Imperial Oil and the University of Toronto Press who made publication possible—to all of these, Canadian aviation owes a very real debt.

It is not an inexpensive book, but for anyone with a serious interest in this country's aviation it is a 'must' for his library and well worth a bit of determined budgeting.

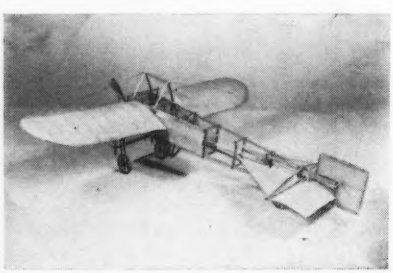
R. B. FERRIS

THE 1910 AIR MEET

SEVERAL interesting letters have been received about the photographs appearing on pages 52 and 67 of the May and June issues. Unfortunately they cannot be published in full and it would be unwise to try to summarise them.

Briefly, the photographs were evidently taken at the first Air Meet held in Canada, at Lakeside near Montreal, from the 27th June to the 5th July, 1910. The event is described very fully in *Canada's Flying Heritage* by Frank H. Ellis, which is reviewed above. A second Air Meet took place in Toronto, at the Trethewey Farm, from the 9th to the 15th July.

One of the two machines shown in the second photograph was the famous Blériot "La Scarabée", which was the second aircraft to fly the English Channel — on the 23rd May 1910. Count Jacques de Lesseps, who owned the aircraft, was the pilot on the cross-channel flight and the star of the Montreal and Toronto meetings.



Mr. J. H. Parkin's model.

An interesting sideline of the Lakeside affair was a model contest which was won by a Blériot XI replica submitted by J. H. Parkin. Mr. Parkin, now Director of the National Aeronautical Establishment, still has the model and we are indebted to him for the photograph of it. It will be realized that model making in 1910 was no mere assembly of kits of parts; there was no wood prepared in appropriate sizes and very little published data to guide the model maker.

(Mr. Parkin's other souvenirs of the event include a tattered cutting from the Montreal "Daily Witness", the newspaper which sponsored the model contest. It records, on the same page, an account of the Jefferies-Jack Johnson world championship fight! That dates it, for those of us whose interest in prize-fighting preceded our devotion to the subtler art of aeronautics.)

SUSTAINING MEMBERS

Of The

CANADIAN AERONAUTICAL INSTITUTE

1955 - 1956

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ON THE VISCOUNT ... AN EMBLEM OF LEADERSHIP

To the expert, the Viscount's turbo-prop Rolls-Royce "Dart" engines mean a remarkably successful alternative to conventional piston propulsion.

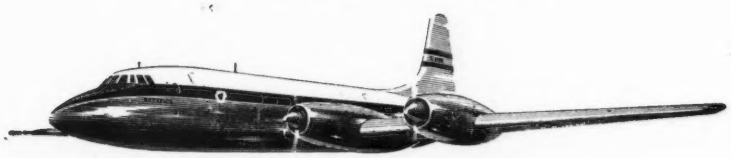
To the passenger, they mean a new kind of ride — the least vibration, the quietest flight of any aircraft in commercial operation.

And to TCA — first on this continent to appraise the basic importance of this new-type engine, first to bring the Viscount to North America — it means a unique opportunity to lead the way into a new era of more comfortable air travel.

The TCA Viscount is now in service on Canada-U.S. and Canadian intercity routes.

TRANS-CANADA AIR LINES

TURBOPROPS



THE MEASURE OF EFFICIENCY of an airliner is its ability to make a profit when carrying fluctuating loads over varying distances. It is not competitive in the world market if it does so only under favourable route and load conditions. The economics depend to a very large extent on engine life, power, and above all, fuel consumption. Modern piston engines run for 1,000 hours between overhaul, give upwards of 3,000 hp and have a fuel consumption of ½ lb per hp per hour, which in a four-engined airliner means about 1 mpg. Turbines can be expected to supersede piston engines only when they are conclusively superior on all counts.

Turbines are of two sorts—the turbojet which delivers its power in the form of an exhaust jet, and the turboprop which uses its power to drive a propeller. Both types of turbine can match the piston engine in longevity and outclass it in power. It is on fuel consumption that the two types of turbine differ. The consumption of the turbojet is about twice that of a comparable piston engine. This would not matter so much if the turbojet could do double the amount of work by flying twice as fast as the piston engine, but in the event an increase in cruising speed beyond about 400 mph does not bring about a commensurate gain in average journey speed. High fuel consumption is therefore a very real difficulty to the turbojet. In order to reduce its fuel consumption as much as possible, the jet aircraft must fly high; it is, in practice, locked inflexibly to a narrow band of altitudes in the fringes of the stratosphere. And the high wind velocities at these great altitudes makes close timekeeping on east-west routes difficult on a year round basis.

In the turboprop the fuel consumption problem is largely mastered because this type of turbine, unlike the turbojet, makes use of the highly efficient propeller. Moreover, the turboprop airliner can cruise economically at any altitude between 15,000 and 35,000 feet and thus, by flying at the appropriate level, can minimise the effect of headwinds and take advantage of tailwinds. This flexibility of operation is a feature of the Britannia airliner which, now in production, is powered with Bristol Proteus turboprop engines. The Proteus 755 develops 4,150 hp and is thus a good deal more powerful than current piston engines. Its consumption is some 10 per cent greater but this is more than offset by using a cheaper fuel.

A pointer to the importance of fuel consumption is that fuel costs amount to the largest single item of operational expenditure in the average airline. Thus the air transport industry's long-range vehicles capable of carrying big payloads at peak periods must also have a fuel consumption which enables them to carry economically the smaller payloads of the off-season. Piston engines do this now and airlines will buy the turbines that can lift bigger loads faster and cheaper. There is a vast world investment in the piston engine and it will only be worth staking the future on a new prime mover that is markedly superior all round. The true civil and military workhorse engine is the turboprop.

THE BRISTOL AEROPLANE COMPANY OF CANADA LIMITED

315.P

CANADIAN AERONAUTICAL INSTITUTE

MEMBERSHIP REQUIREMENTS

Individual membership of the Institute is divided into seven grades requiring qualifications which are defined in Article 7 of the By-laws. These qualifications are summarised in the following table.

GRADE	QUALIFICATIONS	ANNUAL DUES	*SPECIAL ANNUAL DUES
Student	Undergoing a course of study at an approved school of engineering or technology	$1.00	No Dues
Technician	Engaged in technical work in aviation	$3.00	No Dues
Technical Member	Engaged in scientific, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$5.00	$2.00
Member	Engaged in aviation for 8 years and acquired a recognized standing	$6.00	$2.00
Associate	Engaged in aviation though not qualified for technical grades	$6.00	$2.00
Associate Fellow	Engaged in aeronautical science or engineering for 10 years and been in responsible charge or made outstanding contribution	$7.00	$3.00
Fellow	Been an Associate Fellow for 1 year and attained distinction in aeronautics	$8.00	$3.00

APPLICATIONS

Application for membership must be made on the approved form, which can be obtained from the Secretary, and which must be returned to the Secretary on completion. The applicant does not apply for membership in any specific grade, but each application is carefully considered by an Admissions Committee, who submit their recommendations in this regard to the Council. The Council is the deciding body. On admission the applicant is informed of his grading and the appropriate entrance fee and dues.

ENTRANCE FEES

The Entrance Fee is $5.00. Members in good standing in the R.Ae.S., I.A.S., I.A.T. or O.A.S., on the 1st of January 1954, who were resident in Canada at that time, are admitted without payment of entrance fee. Students and Technicians are also exempt from entrance fee but must pay a transfer fee, which is in effect a deferred entrance fee, when they transfer later on to one of the senior grades.

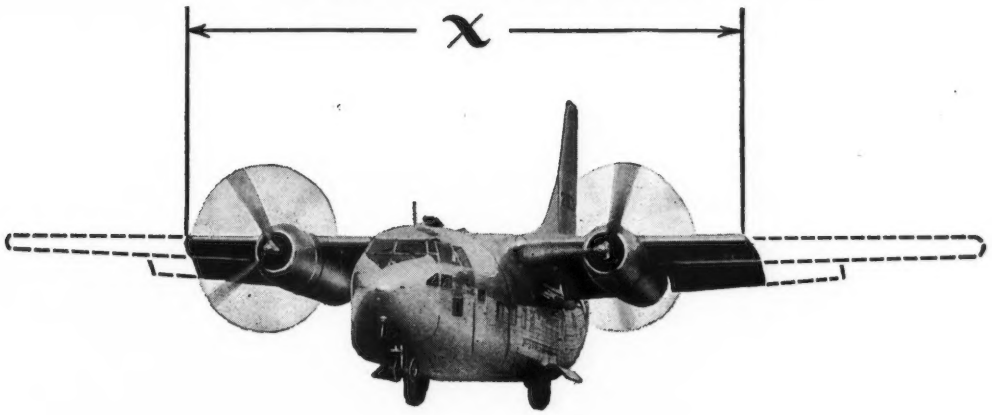
*SPECIAL ANNUAL DUES

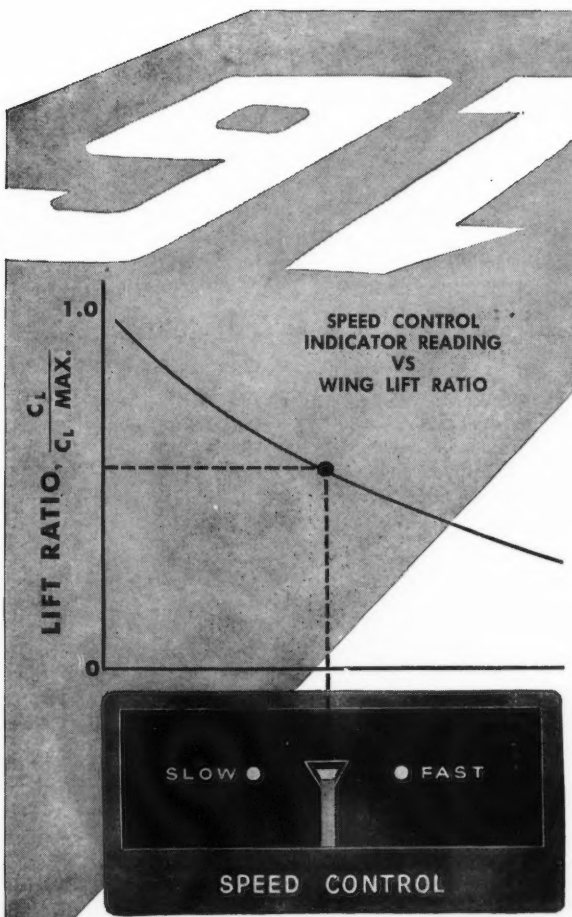
Members of the R.Ae.S., I.A.S. and E.I.C., who are normally resident in Canada, enjoy a reduced rate of annual dues by virtue of the financial assistance which these bodies render to the Institute. This reduced rate is shown in the right-hand column of the above table.

SUBSCRIPTION TO C.A.I. PUBLICATION

In addition to the annual dues, all members are required to subscribe to the publication of the Institute, at a rate set by the Council but not exceeding $3.00 per year.

How much* of the available WING LIFT are YOU using?





Statistics show that less than one half of the available wing lift is being used for the average landing.

The Safe Flight Speed Control System enables you to utilize safely the full wing lift by zeroing-in a perfectly controlled minimum speed landing every time. Very significant advantages are achieved for both jet and propeller driven type aircraft. The Speed Control System presents lag-free rate and trend information which is easy to follow for precise elevator and power control. It automatically compensates for every configuration, weight, and power condition. Approaches, regardless of turbulence or weather conditions, are made precisely, more safely, and with less effort. This system also insures best take-off climb performance.

The Safe Flight Speed Control System is now standard equipment on all Fairchild C 123B aircraft.

**Unused wing lift means longer runway requirements, lower payloads, excessive brake and tire wear, and possibility of overshoots.*

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